DARPA

SPO
Special Projects Office

Affordable Moving Surface Target Engagement (AMSTE)

AMSTE II Bidder's Brief
June 29, 2000
Air Force Research Laboratory

Welcome To AMSTE II Bidders Briefing

Special Projects Office

9:00 am	Welcome and Administrative Comments	
9:15 am	DARPA/SPO Overview	Stephen Welby, DARPA
9:30 am	AMSTE Introduction	Stephen Welby, DARPA
Break		
10:30 am	AMSTE I Program Elements	Jon Jones, AFRL
10:40 am	AMSTE I Results	Robert Enders, MITRE
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Welcome To AMSTE II Bidders Briefing

Special Projects Office

- Purpose: To Clarify and Illuminate the CBD Announcement
  - In case of conflict: CBD Announcement is official governing guidance
  - Briefing will be posted on AFRL Web Site by COB tomorrow

- Introductions:
  - DARPA Program Manager: Stephen Welby
  - AFRL Program Manager: Jon Jones
  - AFRL Contracting Officer: Joetta Bernhard

- Questions and Answers will be Conducted via AFRL Web Site
  - No questions are allowed during the briefing
  - Questions and answers will be published on the Web.
  - Question and answer session open until 7 July 2000, 1600 EDT.

Welcome – Briefing Logistics for the AMSTE II Bidders Brief

Special Projects Office

- Sign In
  - Attendance is being recorded in the lobby
  - An attendance list will be posted on the Web
  - Please check “NO” on the sign in sheet if you do not want your name and company information to be posted
- Security
  - Do not wander out past the glass doors on the left except to use the rest rooms
  - The building is a restricted area and you must be accompanied by a Blue Badge Government employee to go beyond the glass doors
- Restrooms
  - Restrooms are located outside the glass doors immediately on the left Again, do not wander past these facilities
- Lunch
  - A map with suggested lunch places is available at the table outside the auditorium doors

AMSTE II
Bidders Briefing

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Special Projects Office Overview

James F. Carlini, Director

DARPA Current Focus Areas

National-Level Problems

- Protection from Biological Attack
- Protection from Information Attack

Operational Dominance

- Affordable, Precision Moving Target Kill
  - Offensive and Defensive
- Dynamic Command & Control
  - Mobile Networks
  - Near-Real-Time Planning, Replanning
- Future Warfare Concepts
  - Hard and Deeply Buried Target Classification
  - Combined Manned, Unmanned Operations

High-Risk, High-Payoff Technology Exploitation

- Core Technologies
- The Intersection of Biology, Information and Microsystems

2/00

DARPA Organization

Director
Frank Fernandez

Deputy Director
Jane Alexander

Defense Sciences
Michael Goldblatt
Steven G. Wax

- Bio Warfare Defense Technologies
- Biology
- Materials & Devices
- Mathematics

Information Technology
Shankar Sastry
Mark Swinson

- Networking
- Embedded and Autonomous Computing
- User Interfaces & Translation
- Software Composition

Microsystems Technology
Robert Leheny
Ellison Urban

- Electronics
- Optoelectronics
- MEMS
- Combined Microsystems

Advanced Technology
Tom Meyer
William Jeffrey

- Early Entry, Rapid Reaction Forces, Special Forces
- Communications
- Maritime

Information Systems
William Mularie
Kathy MacDonald

- Information Assurance & Security
- Command & Control
- Planning & Logistics
- Asymmetric Threat

Special Projects
James Carlini
Amy E. Alving

- Biological Warfare Defense Systems
- Surface/Underground Target Engagement
- Sensor/Navigation Systems

Tactical Technology
David Whelan
Allen Adler

- Laser Systems
- Future Combat Systems
- Space-Based Sensors for Surveillance and Targeting

Military Assistant
Col R. Kurjanowicz, USAF

Operational Liaisons
Col R. Kurjanowicz, USAF; LTC G. Sauer, USA

Marriage of <u>New Technical</u> Ideas
with <u>Critical National Challenges</u>

- Emphasis on technologies/systems to shape future defense environment
  - Extend air dominance to surface/underground dominance.
  - Plug “holes”.

Counter Emerging Threats

Keep Surface/Underground Targets at Risk

Critical Supporting Technologies/System

Hold Surface Targets At Risk

- Moving, Emitting, CC&D
- Underground Facilities
- Entire Kill Chain
  - –Surv-Combat ID-Engagement-BDA
- Emphasize Robustness

Counter Emerging Threats

- Chem-Bio Defense Systems
- Cruise Missile Defense

Critical Supporting Technologies/Systems

- Navigation
- Advanced Sensors
- Signal Processing

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Affordable Moving Surface Target Engagement (AMSTE)

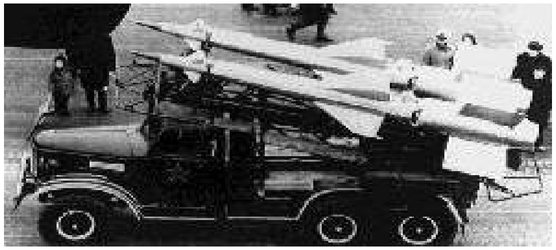
Stephen Welby, DARPA

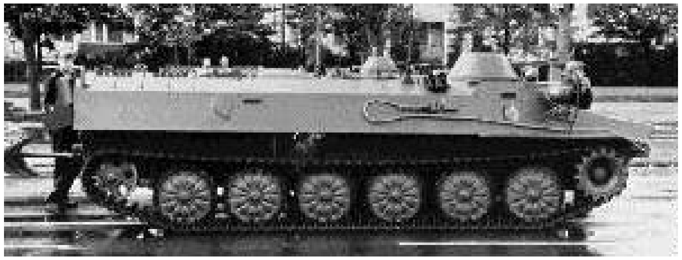
The AMSTE Motivation

- Significant Materiel and Technology Investment has Enabled US Forces to Hold Fixed and Stationary Targets at Risk

- AMSTE Will Extend US Battlefield Dominance to Moving Threats
  - Extend our capabilities to permit all weather engagement of vehicles on the move
  - Deny opponents the sanctuary of movement
  - Destroy enemy's ability to attack, regroup, hide or inflict damage
  - Threat targets have used movement to avoid/hide from US reconnaissance and surveillance sensors
    - Operation Allied Force
    - Operation Desert Storm
  - Time-critical targets move prior to or just after launch
  - Mobile SAMs use movement to avoid targeting
    - Increases SAM location uncertainty
    - Aircrew offensive capability restricted

Mobile Targets





Many Threats… Common Theme: Mobility

Central AMSTE Observation

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Modern Technology Provides Basis for the *Affordable* Precision Targeting of Moving Surface Targets

- Planned GMTI sensors
- Precision weapons
- Communication networks
- High performance processing

Basis for AMSTE is a systems-of-systems approach coupling capable sensors to precision weapons through robust sensor-to-sensor and sensor-to-weapon networks

GMTI Systems

U-2

ARL

JSTARS

Manned Aircraft:
- Stand-off, look in
- Large payload
- Multifunction capabilities
- On-board BM/C3

Fighter MTI

APG-73 APG 63/70
APG-76 APG-78
APG-68 JSF

ASTOR (UK)

RTIP JSTARS

Others:
- Tactical UAV
- Predator
- Special platforms

Global Hawk

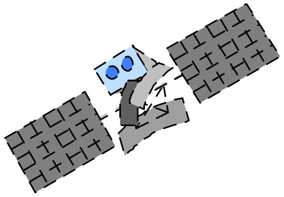
Unmanned Aircraft:
- Penetrating
- Multifunction capabilities
- Low Cost

UCAV

Space based:
- World wide access
- Peace & war
- Ground BM/C3

DISCOVER II
MTI demo

Space Based MTI?



Precision Weapons

- Extended Range Guided Munition / XM-982
- Joint Direct Attack Munition
- Joint Stand Off Weapon
- Joint Air to Surface Standoff Missile
- Small Smart Bomb
- Tomahawk Land Attack Missile
- Tactical Tomahawk
- SLAM-ER
- Guided MLRS

AMSTE Focus

Target *moving* surface threats from long range and rapidly *engage* with precision, stand-off weapons

Key AMSTE Characteristics:

***All-Weather Engagement*:** **Requires use of multi-laterated, geo-registered GMTI sensors**

***Targeting Focused*:** **Requires ability to maintain threat track from nomination through engagement**

***Precision Engagement*:** **Requires ability to provide fire control updates to weapons in flight**

AMSTE technologies support a seamless moving target engagement from Nomination → Track Maintenance → Engagement

The Kill Chain

SURVEILLANCE

- Search
- Detection
- Cueing
- Track Association
- Gridlocking
- Georegistration

FIRE CONTROL

- Precision Track
- Wpn Assignment
- Georegistration
- Track Maintenance

- Handover
- Combat ID

GUIDANCE

- In Flight Update
- Weapon course change
- Continuous footprint update

ENDGAME

- Terminal Homing
- Terminal Maneuver
- Fuzing
- Warhead
- Kill Assessment

AMSTE Overview

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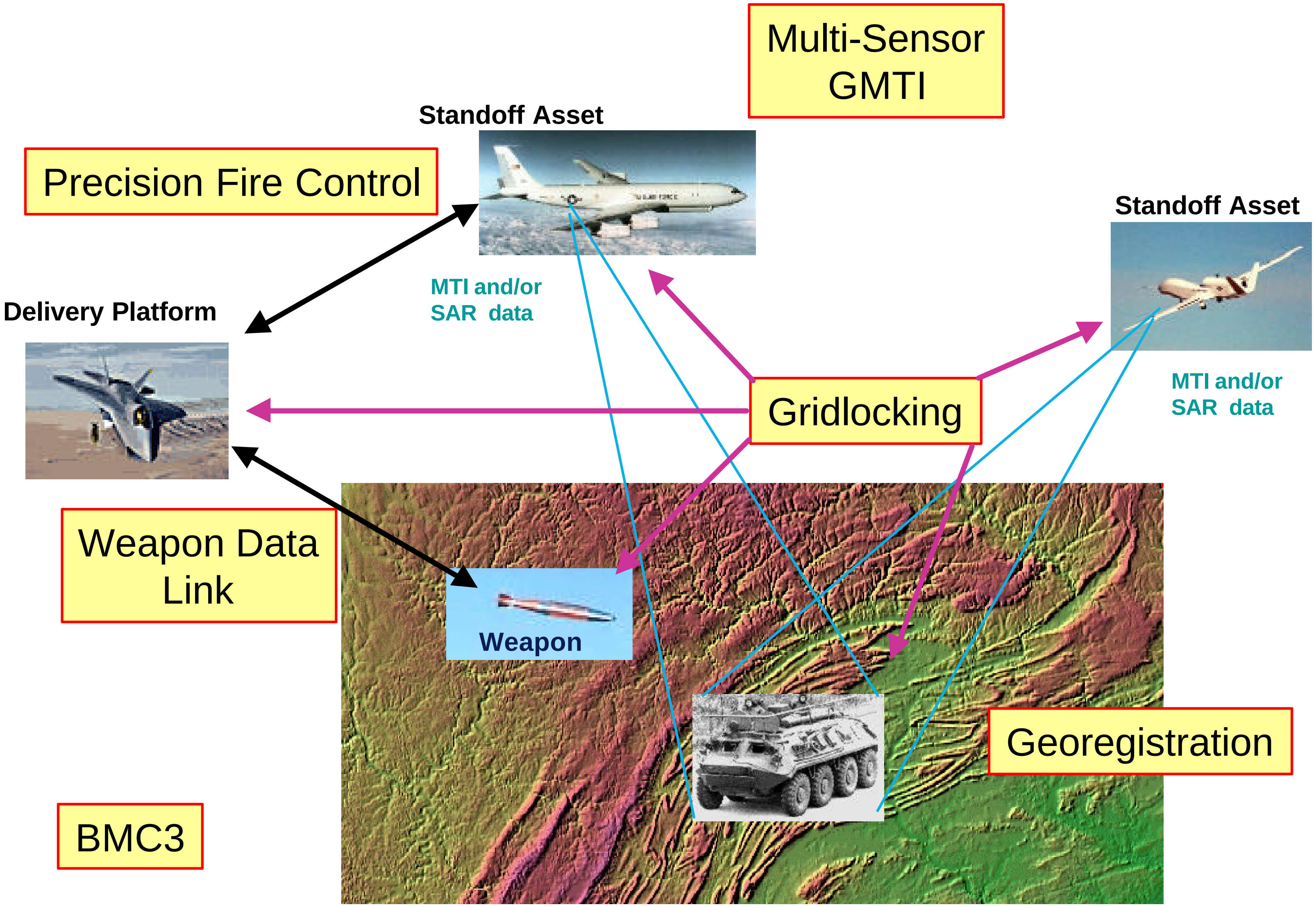


Key Technical Challenges

AMSTE Objective

The AMSTE program will develop and demonstrate a netted system-of-systems approach for:

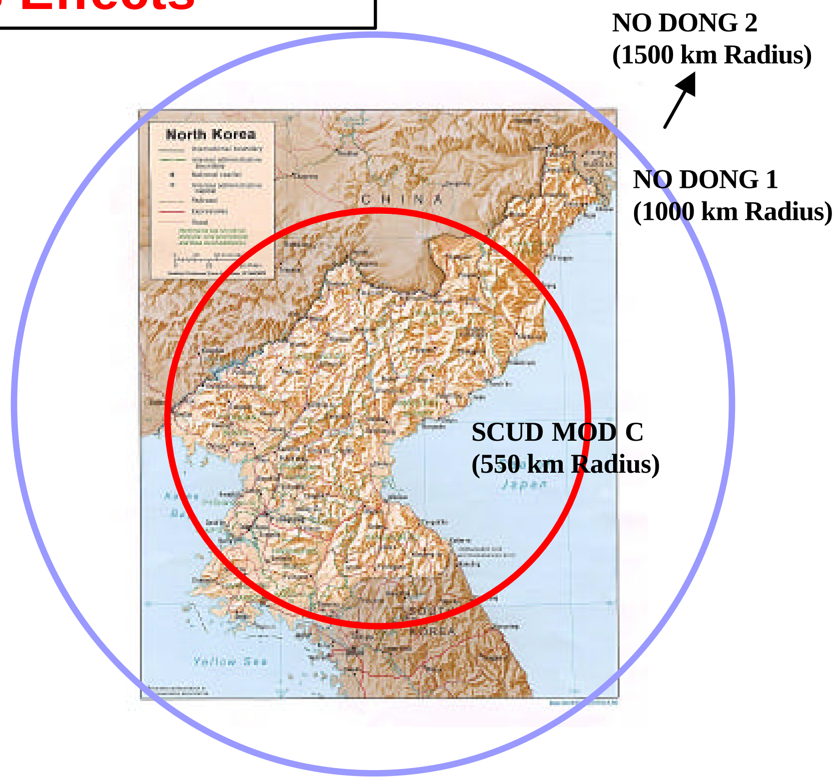
- Networked targeting of moving threats using:
  - Multi-platform fused GMTI
  - Precision fire control tracking
  - Long term track maintenance
  - From tactically significant standoff ranges
  - Against moving and move-stop targets
  - Using guided weapons
  - In adverse weather
  - To deliver <10m CEP

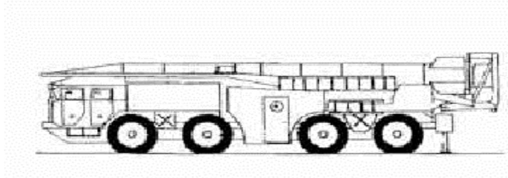
Deny adversaries the sanctuary of maneuver

AMSTE Missions

Counter TBM/TEL
SRBM/MRBM
Weapons of Mass Effects

SS-21





NO DONG 1

Mission Characteristics:

- Vehicles move before and/or after launch
- Vehicle length may provide source for discrimination
- High value assets are defended through move/stop/hide tactics
- Launch ranges force mid to deep strike
- Cue may be provided through DSP, IMINT, COMINT
- Long term tracking of vehicle may be required
- Target density probably low

JDEAD:
Mobile SAMs

Enemy using mobility for defense survivability
- Nontraditional movers (SA-2 in Iraq)
- Highly mobile designs (SA-6/8/10/12/15/17)

Blue aircrew offensive capability is restricted
- Mission planning difficult
- Forced to reactive defensive maneuvers
- Increased potential for mission kill through stores jettison

<u>Mission Characteristics:</u>

Most SAMs can not shoot while on the move
Cue may be provided through tactical ELINT, IMINT, COMINT etc.
Potentially compressed timelines - typical movement 5 - 20 minutes
High value kill for blue forces
Tactical SAMs may be constant movers
Targets may move in groups of TELARs/FCRs

AMSTE Missions

- Combat Search and Rescue
- Amphibious Attack Support
- Special Operations

Geographic region defined by surveillance
Information passed to engagement sensor
Targets entering kill box are valid strikepoints

Serbia

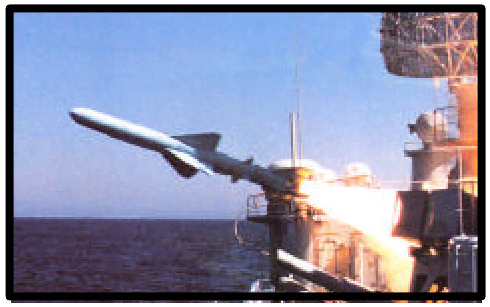
Mission Characteristics:

Common kill box between surveillance and shooter
Combat ID is less restrictive
Threat may be low (Amphib) or high (CSAR): requires short and long range standoff
Moving targets are **the** prime interest
Target density may be high

- Anti-Surface Warfare
Fast Attack Boats

Surveillance identifies hostile inbound to blue forces
Precision track maintained on surface boat
Fleet defense engages - either from air or surface (ERGM)

Chinese Houxin Boat



CS-801

Fast Attack Boats

<u>Mission Characteristics:</u>
Combat ID as hostile is easier (positive ID may be hard)
Threat to launching platform is low
Length may be a discriminator (200 ft for Houxin)
Target density is low

Target Characteristics

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- SAMS
  - Mobile: Tactical SAMs may move 3 - 40+ miles every day or two
  - On and Off road, although roads are primary means of movement
  - In groups of FCRs/TELs and support equipment (1/2 dozen+)
- SRBM, MRBM
  - Mobility is survivability. Move frequently and stop/hide for long periods
  - On and off road
  - Tend to be single target or fewer smaller accompanying trucks
- Trucks, APCs, Light Armored Vehicles, Mobile C^2 Vehicles
  - Quick movement with frequent acceleration/deceleration
  - Mainly on road
  - Larger Numbers
  - Trying to get to the fight quickly (downed pilot, amphibious attack forces, command and control etc)
  - Softer targets
- Fast Attack Boats
  - Up to 1400 miles range
  - 35 knot speed
  - Small numbers - single or few ship operations

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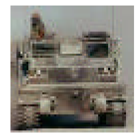
AMSTE Service Spectrum

	Near	Mid	Deep
Army	• GMLRS 	• GMLRS 	• ATACMS 
Navy	• ERGM 	• JSOW 	• SLAM-ER 
Air Force	• JDAM 	• ER JDAM 	• JASSM 

Netted sensors and precision fire control enable many solutions across all services

Summary

- Moving Surface Target Engagement is a Critically Needed National Capability
- Moving Surface Target Engagement Supports Multiple Services, Multiple Mission Concepts
- DARPA's AMSTE Program is Investigating, Developing, and Evaluating Technologies to Support the *Affordable* Engagement of Surface Moving Targets.
- DARPA/SPO is Preparing to Demonstrate Key Technologies for Moving Surface Target Engagement
- Key Technical Challenges Remain
- In AMSTE II Prime Contractor shall
  - Develop AMSTE system technologies;
  - Integrate into an experimental system and
  - Conduct experimentation and demonstration with the experimental AMSTE system
- Three Year Plan for Increasingly Difficult Tests to Demonstrate Relevant Technologies

AMSTE I: Accomplishments

- Weapon System Trade Study
  - Feasibility/affordability assessment
  - Identified critical system components
- Precision Fire Control Tracking
  - Developed and evaluated advanced multi-lateration tracking algorithms
- Data Collection and Simulation of Multiple Platform GMTI Data

AMSTE I Showed Feasibility of AMSTE Concept;

AMSTE II Will Focus on End-to-End System Issues Required to Implement Total AMSTE Solution

AMSTE II Bidders Briefing

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AMSTE I Program Elements

Jon Jones, AFRL

Original AMSTE Program

Weapon System Trade Study

- Sensor and weapon mix analysis
- Experiment design

Precision Fire Control Tracking

- Fire control tracking algorithm development
- Non-Real Time laboratory tracking experiments

GMTI Data Collection

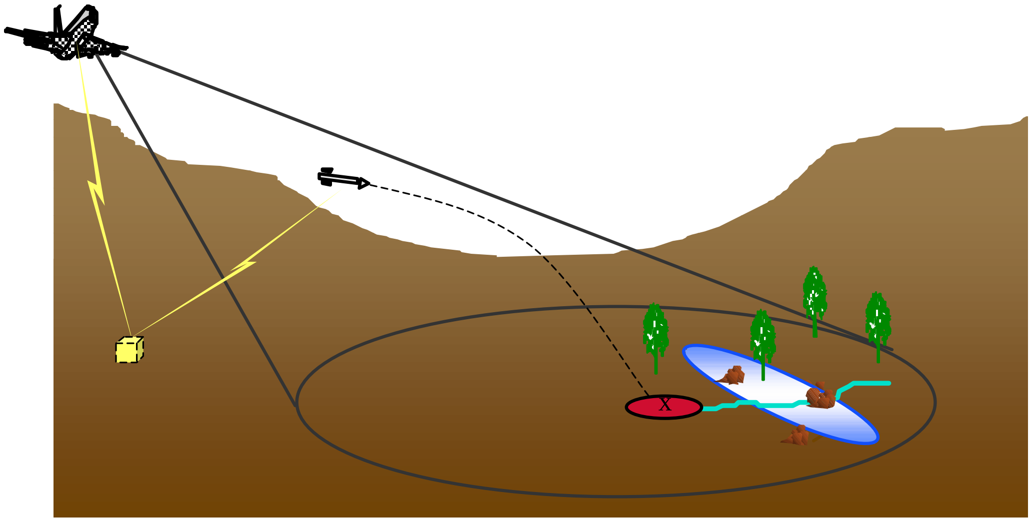
- Multi-platform high-resolution GMTI data collection
- Collection of signature data

WSTS Direction

- Can we build an affordable, militarily useful, all-weather, precision moving surface target engagement capability?
  - For which scenarios/architectures?
  - How does it compare with “conventional” approaches (affordability, performance, ancillary benefits)?
  - What kind / how many sensors are needed?
  - What are the network / data link requirements?
  - What is the best trade between fire control tracking accuracy and weapon “smarts”?
  - How would a system be used in combat?

PFCT Summary

- Develop automated algorithms to register, geo-locate, track, and project moving surface targets
  - – Ground vehicles
  - – Small boats in littoral regions
- This effort is primarily an experimental task to evaluate and understand tracker performance over a diverse trade space
  - – "When do advanced trackers work; when do they fail?"
  - – Overall utility depends upon weapon systems
- Products
  - – Tracker results
  - – Track projection files calculated over track histories
  - – Intermediate tracker products as required to support WSTS
  - – Documentation and reporting



PFCT Track Research Goals

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- Data fusion of detections from multiple sensors
- Processing of out-of-sequence measurements
- Tracking through move-stop-move maneuvers
- Removal of time-dependent systematic bias errors
- Ingestion of external data (e.g., roads, terrain, signature data)
- Interacting Multiple Models (IMM)
  – Number and types of models
  – Management of model mixing and transition probabilities
- Multiple Hypothesis Tracking (MHT)
  – Resource management of hypotheses

GMTI Tracker Challenges

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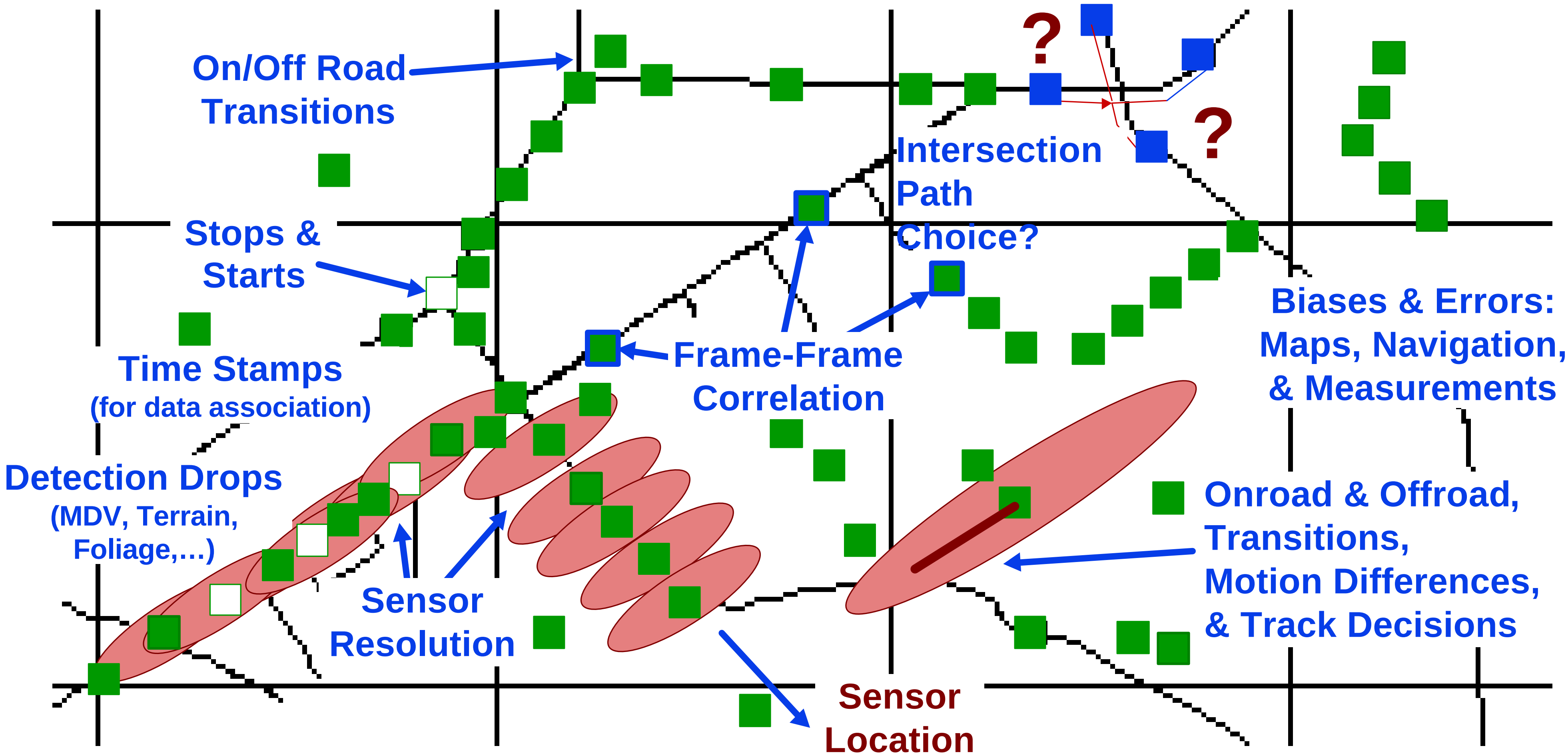

Tracking in Dense & Mobile Target Environments is Challenging

Tracking Experiments

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- Non-Real Time Experiment 1 (NRT1)
  - Objective: Track accuracy with multiple GMTI sensors
  - NRT1: Holloman AFB real vehicle motion data
    - Assess track accuracy versus number of sensor platforms and sensor performance, using simulated GMTI data
- Non-Real Time Experiment 2 (NRT2)
  - Experiment NRT2a: Simulated Kosovo Scenario
    - Assess track continuity versus target density using simulated movements and GMTI data
  - Experiment NRT2b: Instrumented Service Exercise
    - Assess track continuity with synthetic GMTI data based on GPS collections during Ft. Stewart ASCIET exercises
  - Experiment NRT2c: Patuxent (Pax) River Data
    - Assess track accuracy with real GMTI data from multiple platforms

Data Collections

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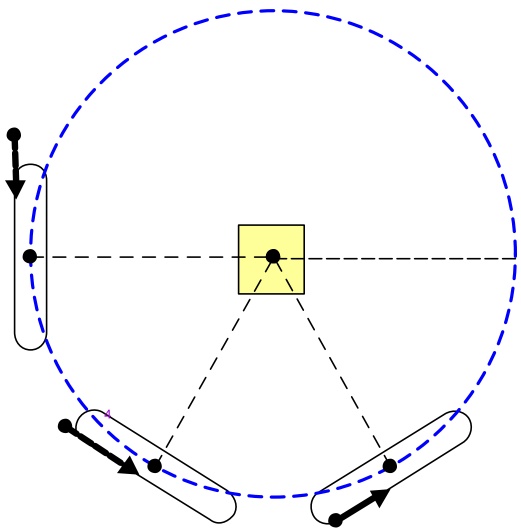
- Data Collection #1: Holloman precision ground truth data
  - Validate quality of ground truth (< 1 m position accuracy, 2 Hz sampling)
  - Data collected on 28 vehicle motion vignettes (~ 40 minutes each)
  - Data was used in PFCT Experiment 1
- Data Collection #2: Pax River Multiple-platform GMTI data
  - Simultaneous data collected from 3 GMTI sensors
    - 4th Gen - Northrop Grumman fighter radar surrogate
    - APY-6 - Northrop Grumman standoff radar surrogate
    - Lynx - Sandia Laboratory standoff radar surrogate
  - Data was used as part of PFCT Experiment NRT2c.

Tracker Experiments

Use of real or simulated vehicular ground truth



Test Point Definition
Variation of Sensor Parameters

AFRL GMTI SIMULATOR

Scenario Files

GMTI Data

CONTRACTOR TRACK PROCESSING

Real multi-sensor data collected Oct 99 at Pax River

Track Log Files

Truth Data: Instrumented Vehicles

Measures of Performance PROCESSING

PLOTS

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AMSTE I Results

Robert Enders, MITRE

Outline

- Weapon System Architecture Concepts
- AMSTE Engagement Phases
  - Track Maintenance
  - Endgame
- PFC Tracker Experiments and Data Collections
- Summary Comments

Weapon System Architecture

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- The WSTS reports in AMSTE I have proprietary aspects

- Offerors for AMSTE II should concern themselves with developing their own architectures
  - exploiting their own strengths
  - utilizing the most effective outside resources they can access.

- The following weapon system architecture slides summarize Core Team work.

Architecture Concepts

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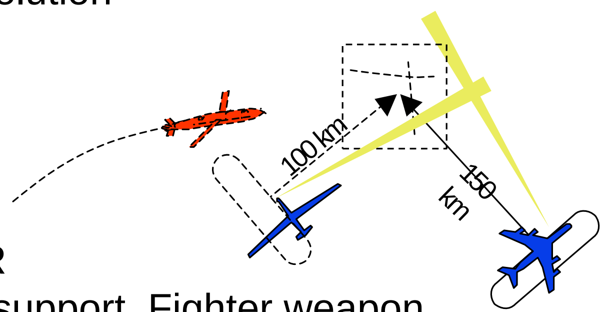
(1) ISR Sensors Only

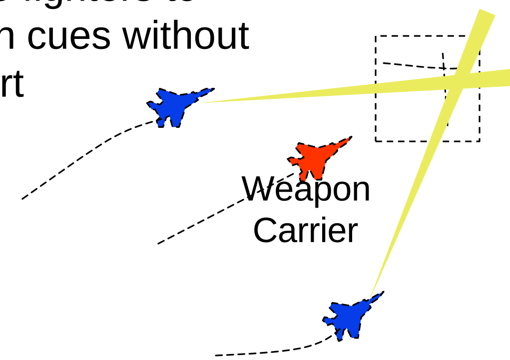
Concept: Use multiple MTI/SAR standoff platforms to provide track maintenance and endgame targeting solution



Variants:
- Single ISR, Two ISR
- Artillery, Naval Fire support, Fighter weapon
- Command guided w/ or w/o seeker on weapon

(2) Fighter Sensors Only

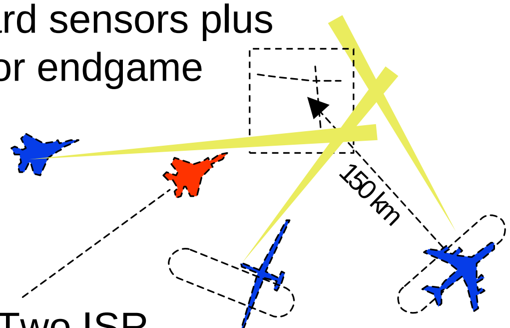
Concept: Use multiple fighters to respond to nomination cues without interactive ISR support



Variants
- Two, Three, or Four ship (1 ship is weapon carrier)
- Command guided w/ or w/o seeker on weapon

(3) ISR Augmented with Fighter Sensor

Concept: Use ISR(s) for track maintenance, handoff engagement control to fighter who uses onboard sensors plus receives measurements for endgame tracking



Variants:
- Two Ship with One ISR, Two ISR
- Active vs. Passive fighter sensor
- Command guided w/ or w/o seeker on weapon

- **Evaluate end-to-end performance**
  - Ability transition through kill chain
  - Ability to maintain track
  - Ability to achieve precision engagement
- **System limitations**
  - Target behavior and background traffic
  - Sensor coverage gaps (masking, turns, FOR)

Scenarios for Analysis

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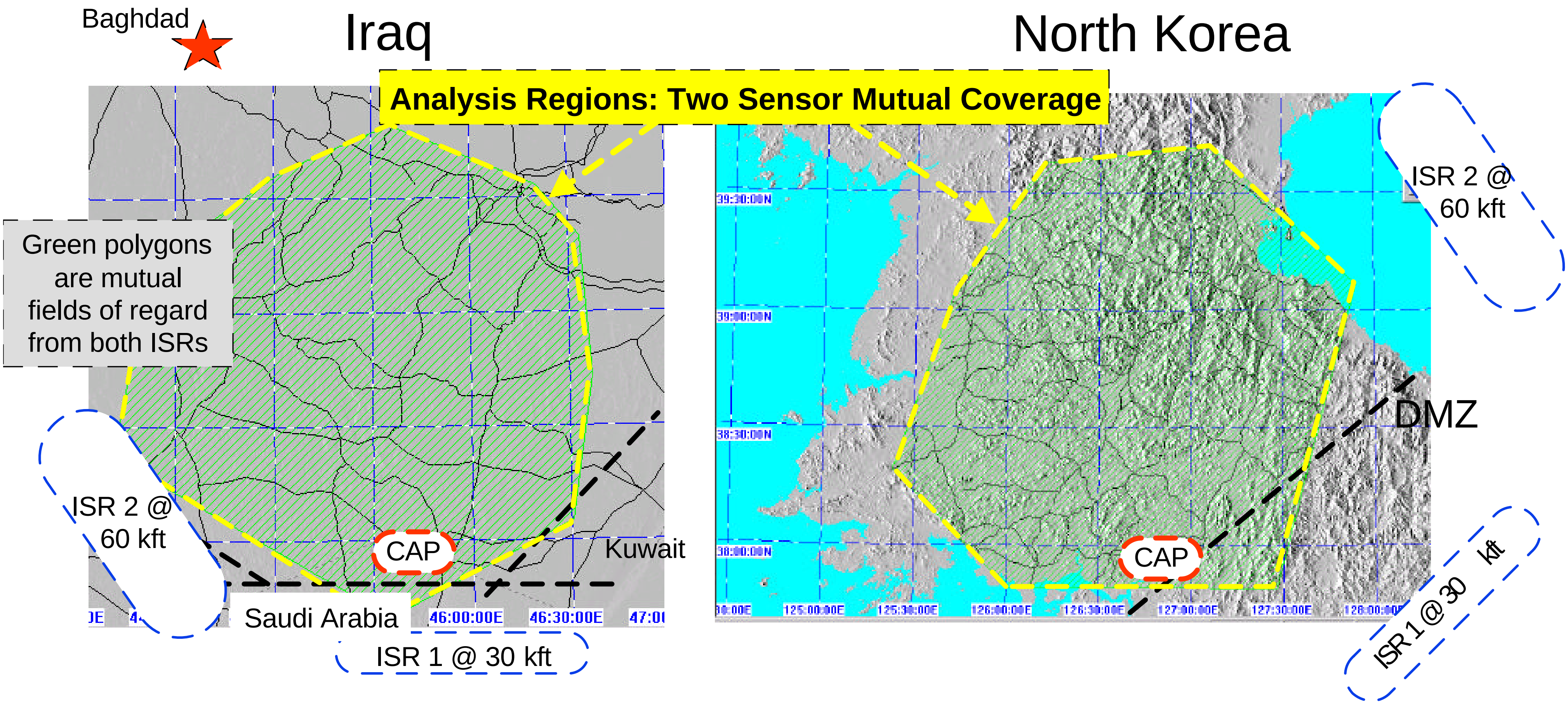


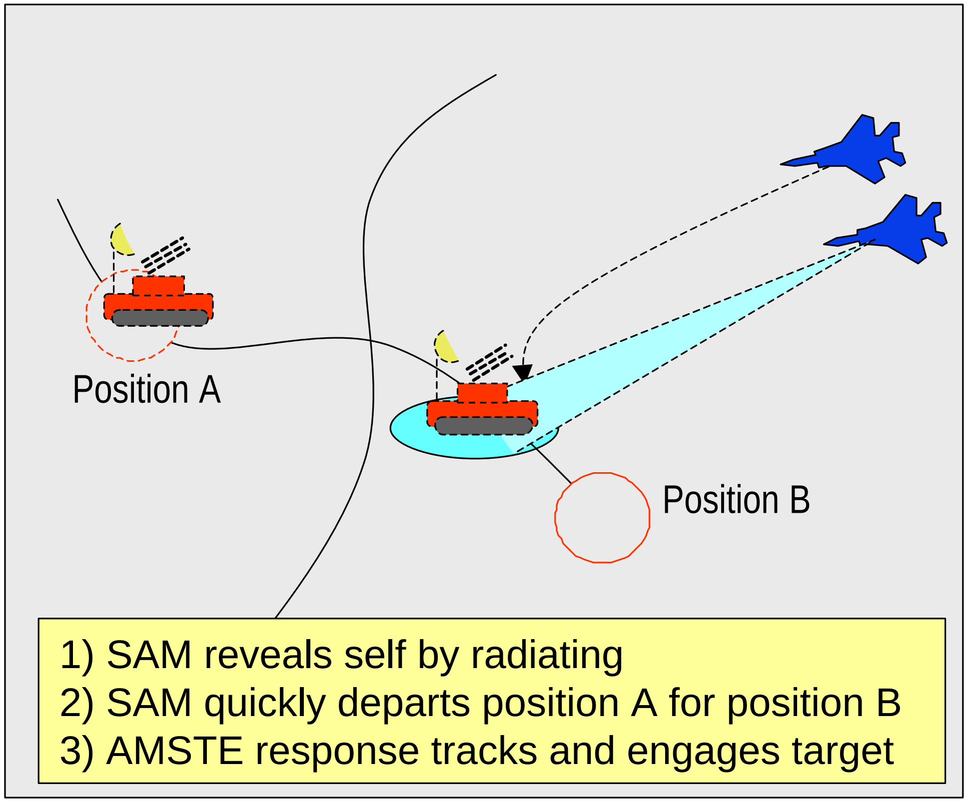
- Real world geo-political scenarios determine standoff asset placement
- Extremes of terrain relief represented
  - Iraq highlights performance in flat terrain
  - North Korea represents mountainous terrain challenge

Mobile SAM Mission

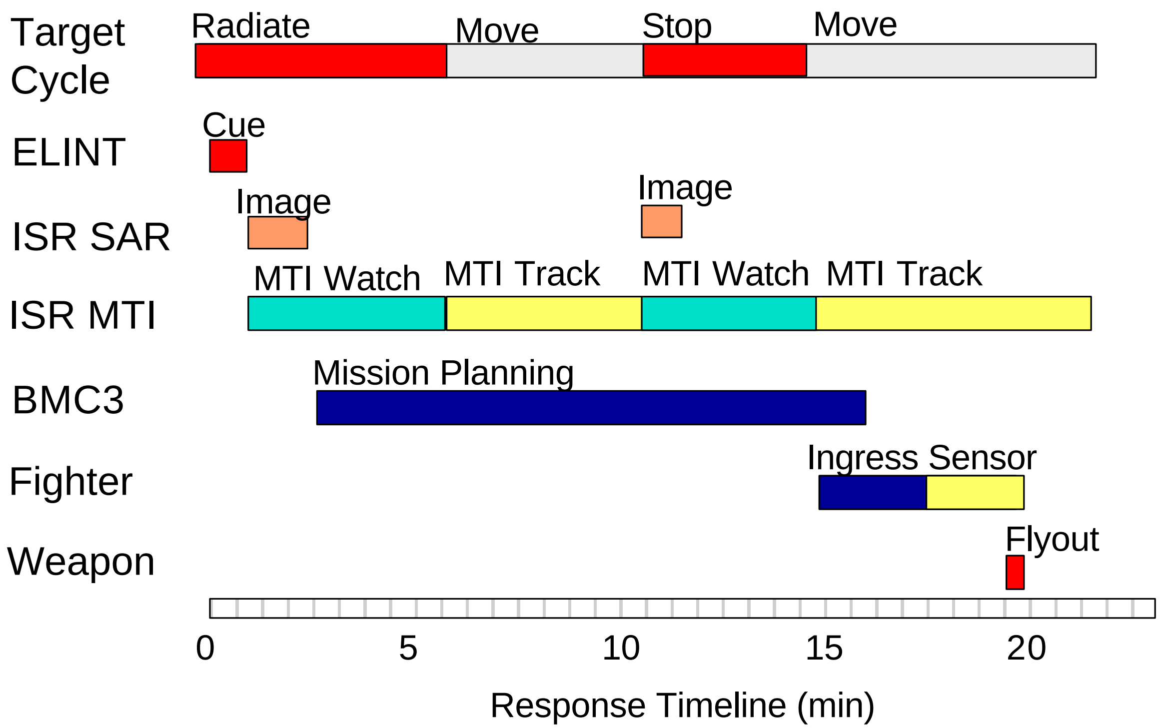
	Time From Nomination Cue (minutes) →											
	5	10	15	20	25	30	35	40	45	50	55	60
SA-6 SAM	Stop	Move			Stop				Move			

AMSTE Response

- **Mission:** Use AMSTE response to suppress mobile SA-6 SAM units
- **Nomination:** ELINT is able to geolocate mobile SAM unit and cue AMSTE response
- **Strategy:** Use AMSTE track maintenance and precision engagement
- **Environment:** Iraq and North Korea
- **Background Traffic:** Sparse
- **Measure of Success**: Vehicle kill



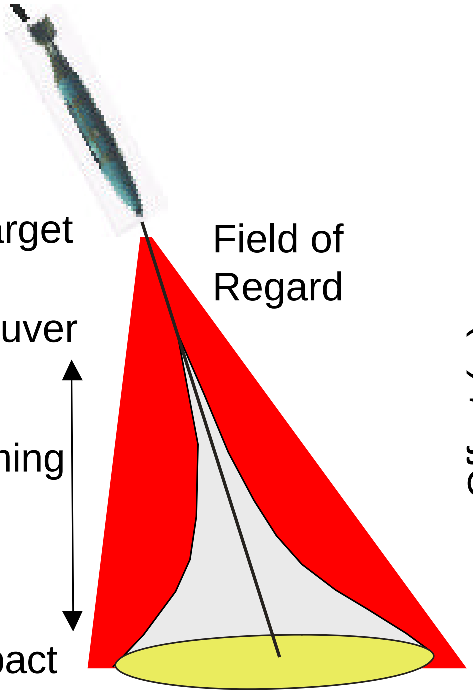
AMSTE System Response



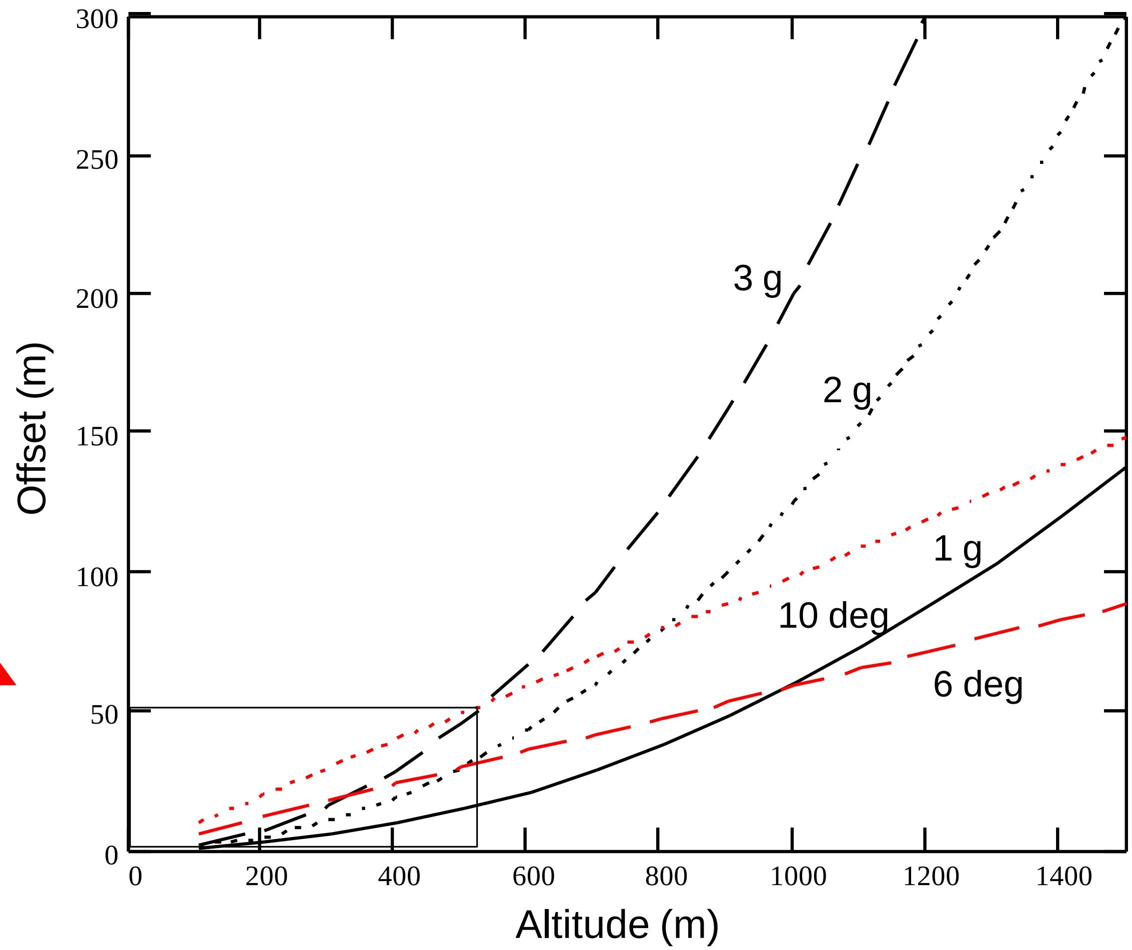
- Target radiate-move-stop cycle
- Respond to ELINT Cue
- Use Imagery for Combat ID
- Track targets from watch box
- Authorize and plan engagement
- Attacker ingress with sensor
- Weapon release and guidance

- System response requires seamlessly moving target through kill chain elements--engagement phases.
- Coordination and availability of GMTI and SAR modes is needed to track through move-stop-move cycles.
- Response time is limited by BM/C3 authorization, planning, and tasking

Seeker Coverage



Seeker Field of View and Weapon Divert Capability



With a 500 m cloud deck, an IR seeker requires handover basket < 50m

Outline

- Weapon System Architecture Concepts
- AMSTE Engagement Phases
  - Track Maintenance
  - Endgame
- PFC Tracker Experiments and Data Collections
- Summary Comments

AMSTE Engagement Phases

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Situation Awareness
•Nominate targets

Track Maintenance
• Maintain target location
• Plan Engagement

Endgame
• Precision tracking
• Conduct engagement

Engagement Timeline

Transition

Transition

BDA

Begin AMSTE Response

Weapon Release

Seeker Acquisition

Impact

BM/C3 Functions (runs through all phases)

- Target identified and nominated for attack

- Initiate AMSTE response
- Assume track maintenance responsibility
- Task and coordinate sensors
- Mission planning
  - Check availability
  - Choose best response option
  - Allocate communication links
- Receive mission authorization
- Transition to attack element

- Acquire target and track
- Attack element assumes fire control
  - Initiate fire control tracking
  - Final authorization
- Weapon release
  - Seeker acquisition, if seeker used
- Battle damage assessment (AMSTE functions end prior to BDA)

Battle Management/C3

DARPA is working directly with service partners to ensure technologies support the warfighters' needs and to develop complementary doctrine

- Why are current timelines so long?
  - Engagement of movers must be coordinated with ongoing operations
  - Multi-step process in current AOC:

    Targeting Decision
    Commanders Review
    Political and Legal Review
    Platform Selection
    Target-weapon pairing
    Threat Assessment
    4-D Deconfliction
  - Effective AMSTE requires ability to execute a "two-minute drill"
    - Critical processes must still be performed, but timelines must be compressed if we are to engage within moving target reaction time constant
  - Netted tracking requires coordination of assets operating in different "stove-pipes"
- How are these issues being addressed?
  - Engaging users in parallel ConOps development
  - Leveraging experience with TCT and TMD Cells in Joint Exercises
  - Experimentation with Command and Control Cell at Nellis for JEFX2000 available for collaborative experimentation with real and simulated operations
    - Coordination with HQAF, ACC, AFC2 BattleLab and others underway

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Track Maintenance Issues

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Track maintenance: the important metric is the length of time track ID can be correctly maintained for a target nominated for kill.

Architecture Factors

- Number of sensors
- Time in turns (on-station duty factor)
- Measurement accuracies (R, Az, R-dot)
- MDV
- Probability of detection
- Revisit rate

Environmental Factors

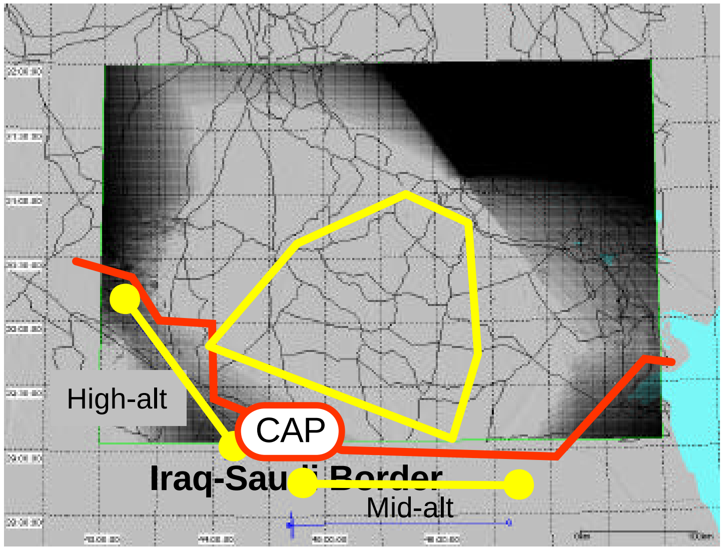
- Target behavior
- Terrain obscuration
- Traffic density
- Road topology

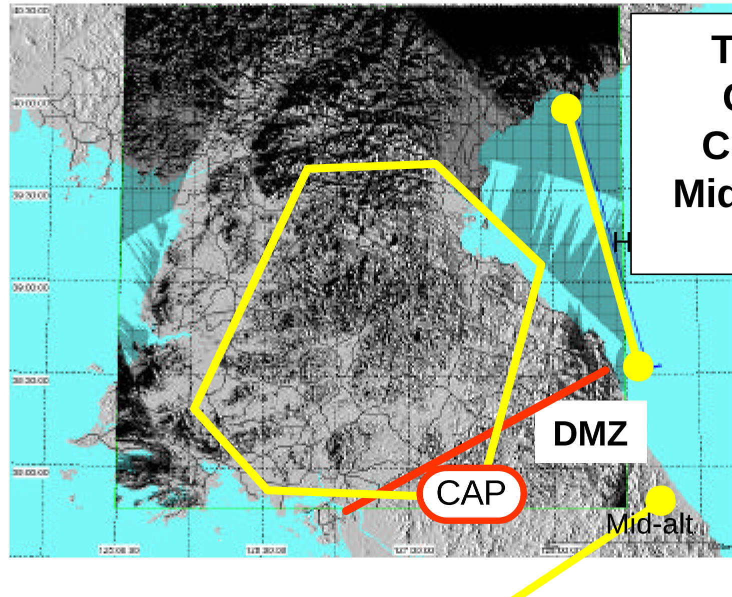
Issues Addressed

- Availability: Can the architecture provide sufficiently frequent target measurements given the geographic constraints?
- Time in track: How long can the architecture maintain track as a function of traffic density and revisit rate?

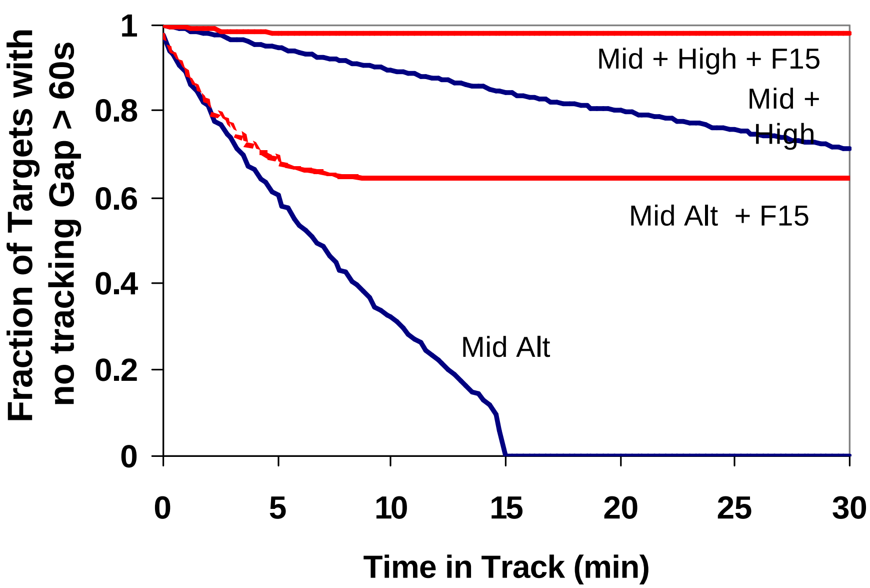
Tracking Sensor Coverage

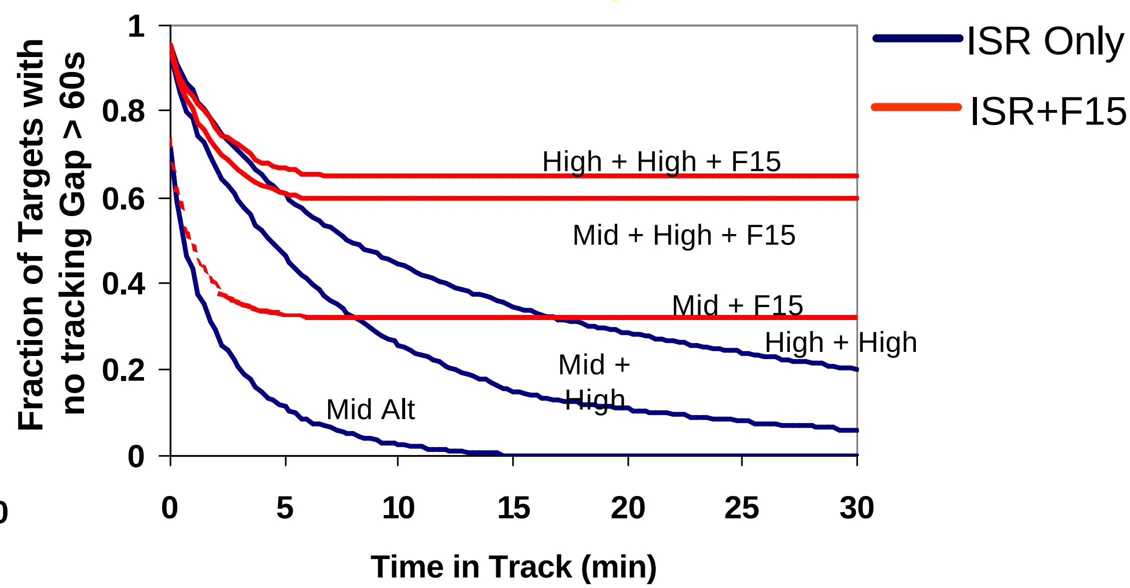
Special Projects Office



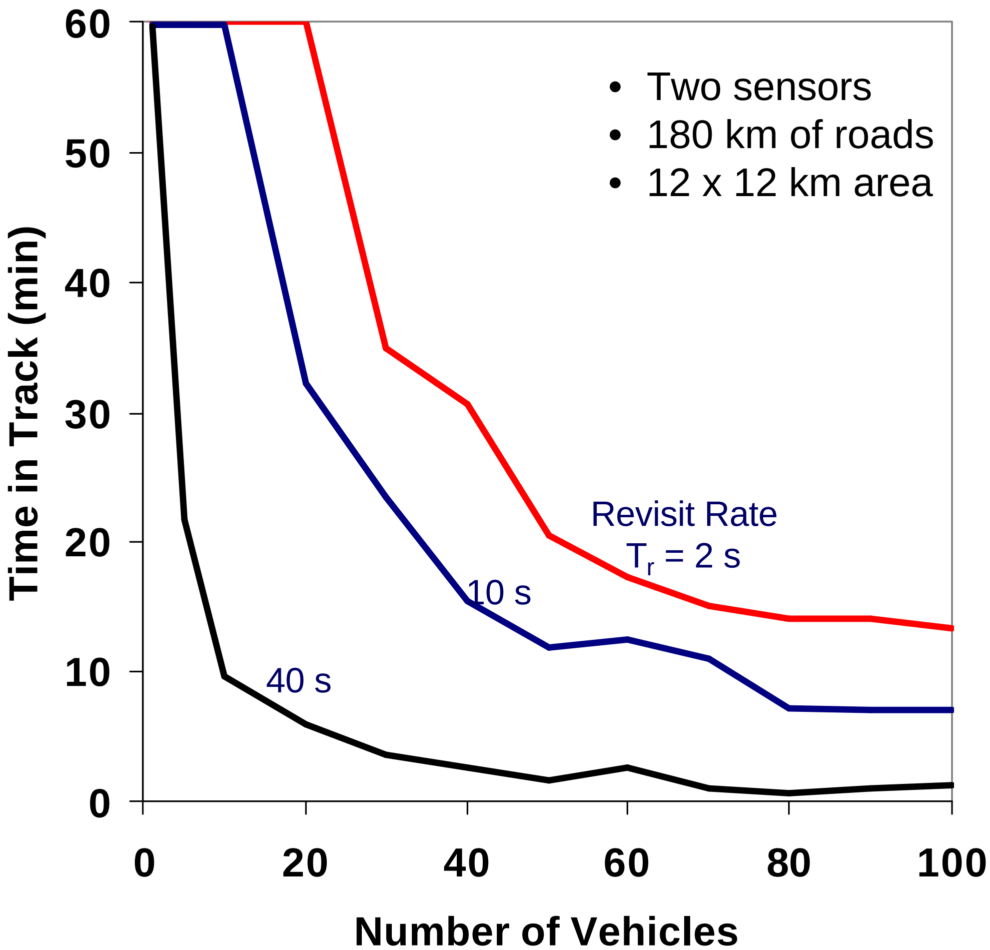


Two Platform Cooperative Coverage Map Mid-alt + High-Alt Example





Track Maintenance
Kinematic Performance



Analysis

- Evaluate kinematic tracking performance

Observations

- Kinematic track performance dominated by traffic “encounters”
- Higher revisit rates help

Kinematic tracking alone is insufficient for long duration track

Track Maintenance
Feature Aided Track Performance

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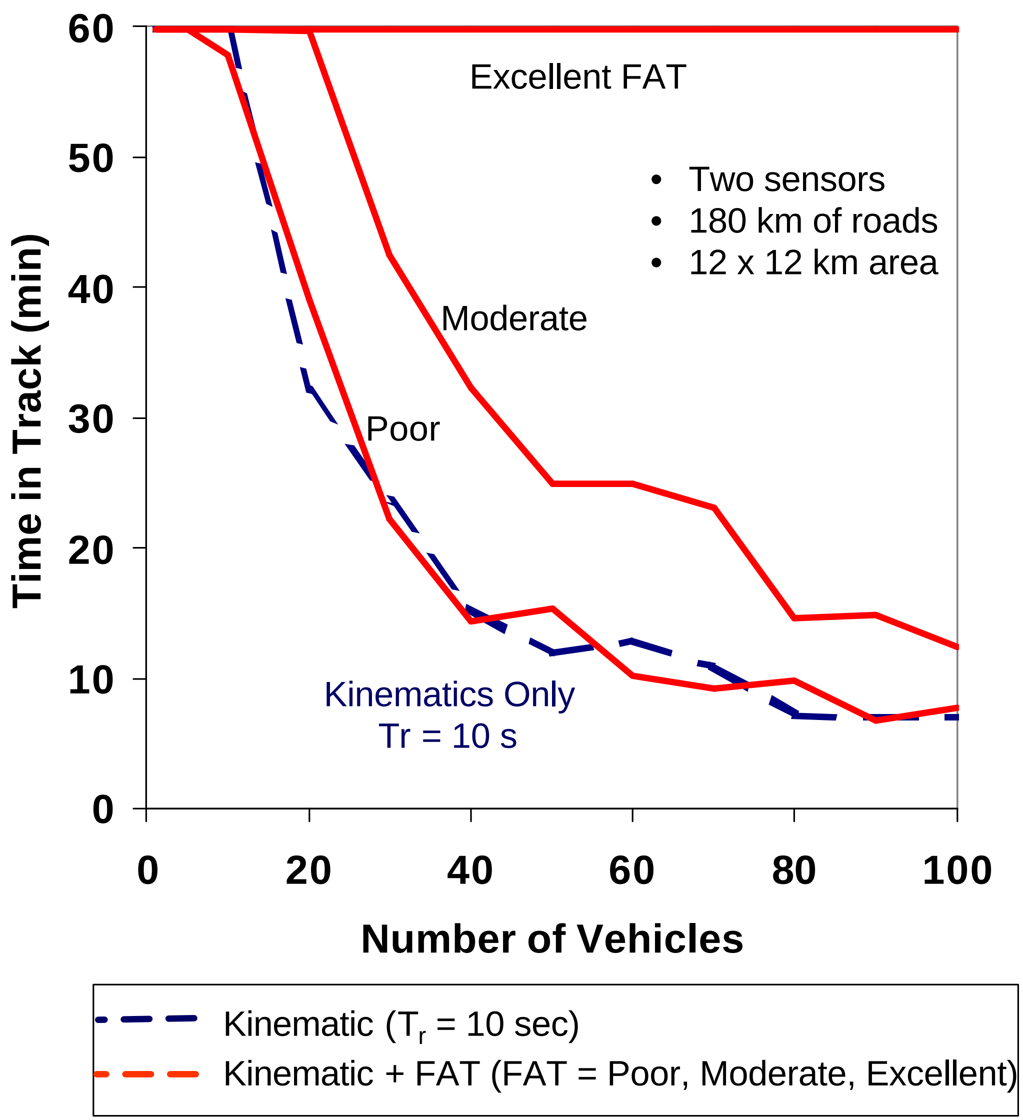

<u>Analysis</u>

- Evaluate FAT tracking potential
- Assume ROC curve performance (poor FAT, moderate FAT, excellent FAT)

<u>Observations</u>

- Signature features could enhance tracking performance
- Poor FAT performance yields no improvement over kinematics alone
- Moderate FAT performance provides some benefit
- All ROC performance is purely notional; not representative of any specific FAT technique

Track Maintenance Insights

Special Projects Office

- Two platforms are required to eliminate coverage gaps during periods of aircraft turns and masking outages
  - Resource tasking and allocation may strain ISR systems
- Kinematic tracking alone works best when traffic is sparse or system response times are expected to be short
  - Association performance governed by background traffic encounters
  - Performance improves with revisit rate and measurement accuracy
- Feature aided tracking shows potential in dense traffic
- Use of fighter as dedicated sensor can decrease the length of time ISRs need to maintain track

Maintaining track may be the most difficult technical challenge

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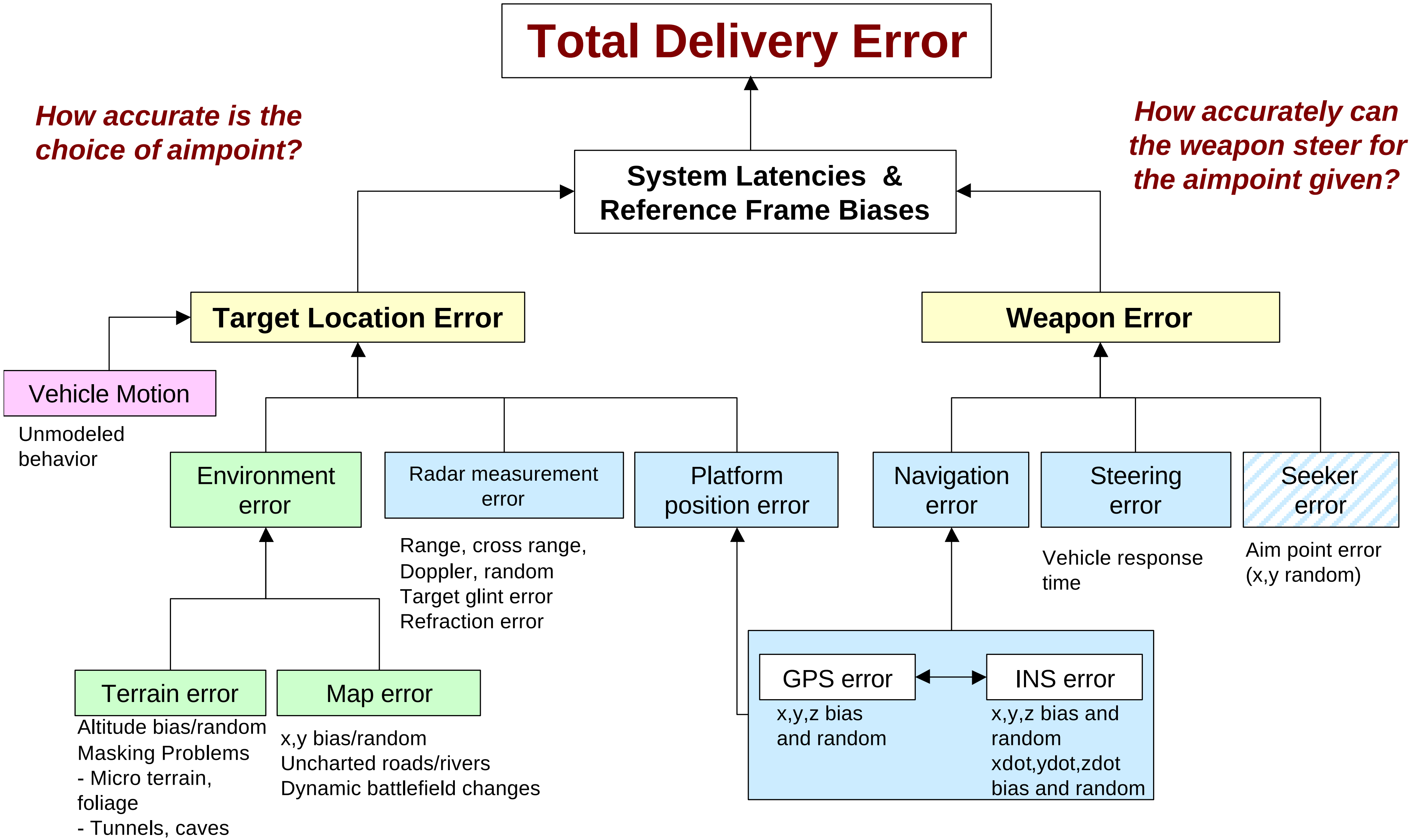
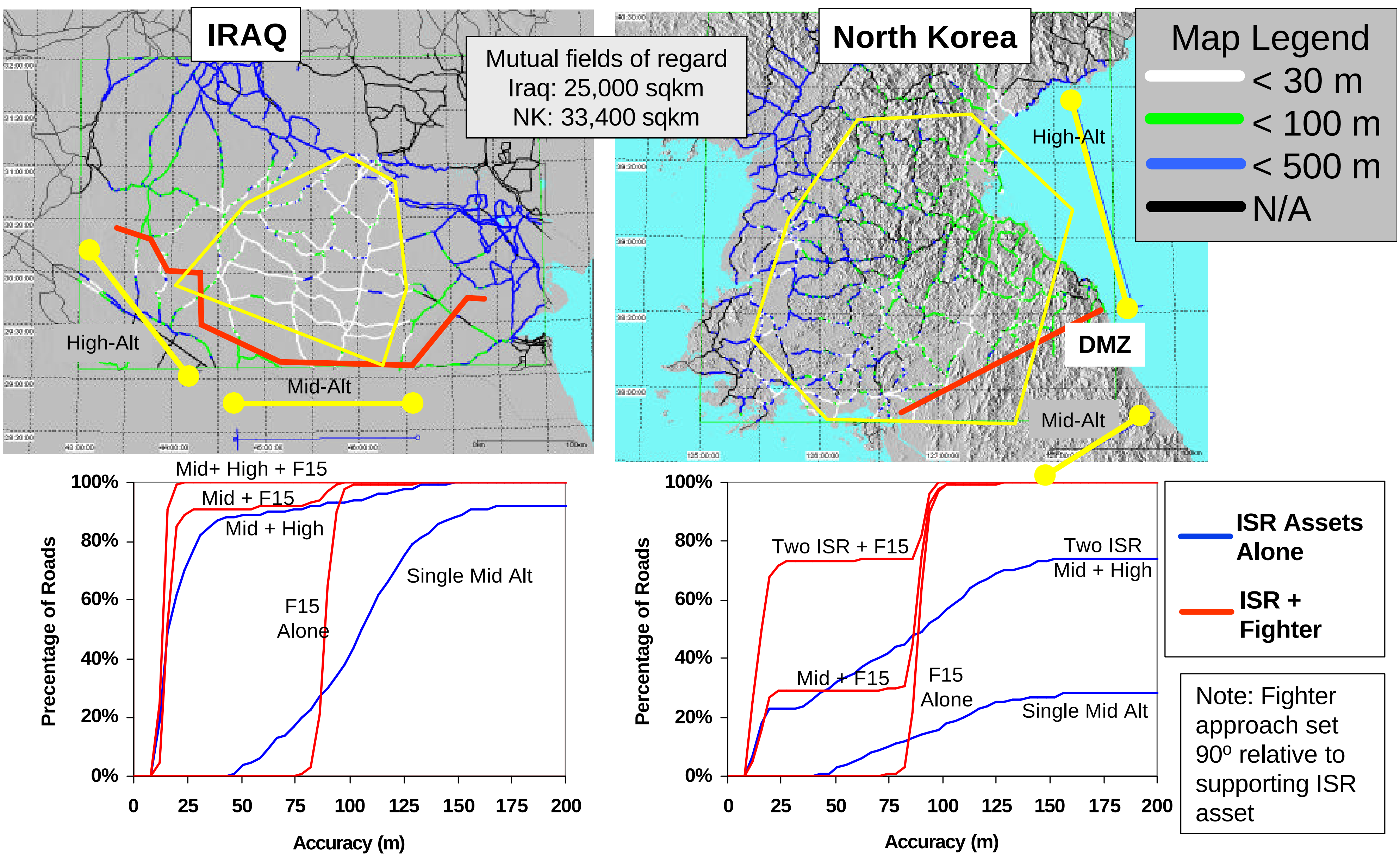
Endgame Errors



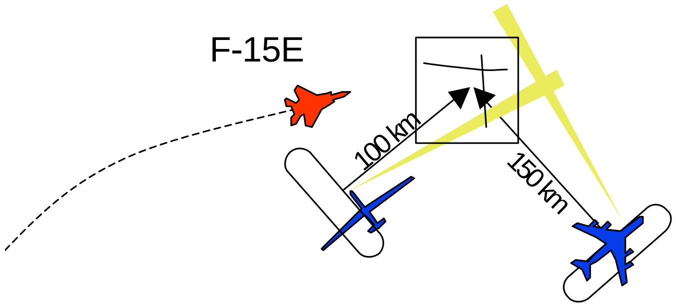
Endgame Track Accuracy

Availability

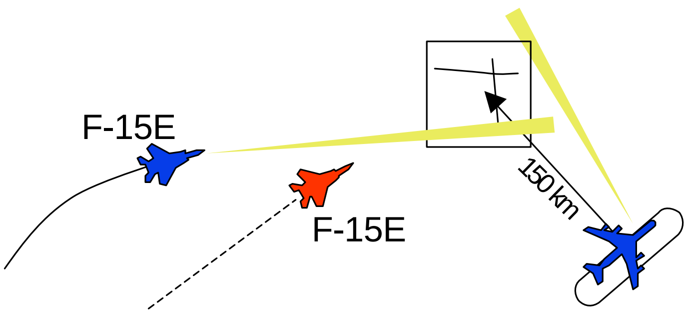


Endgame Performance Results
--Architecture Comparison--

ISR Sensors Only

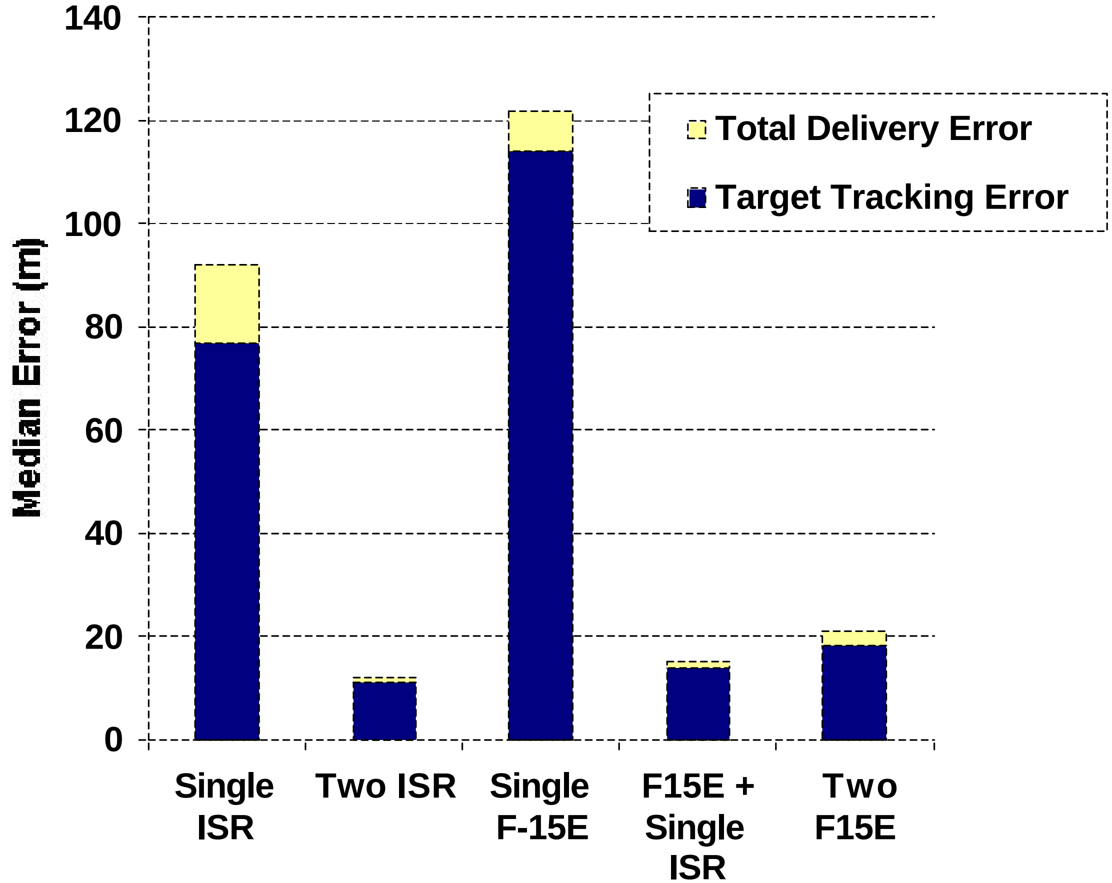


ISR Augmented with Fighter GMTI Sensors



* Analysis excludes weapon navigation and bias errors

Simulation Results



Track error is more significant than weapon guidance errors

Biases and Gridlocking

Gridlocking of sensors and removal of absolute biases remain one of AMSTE's key technical challenges

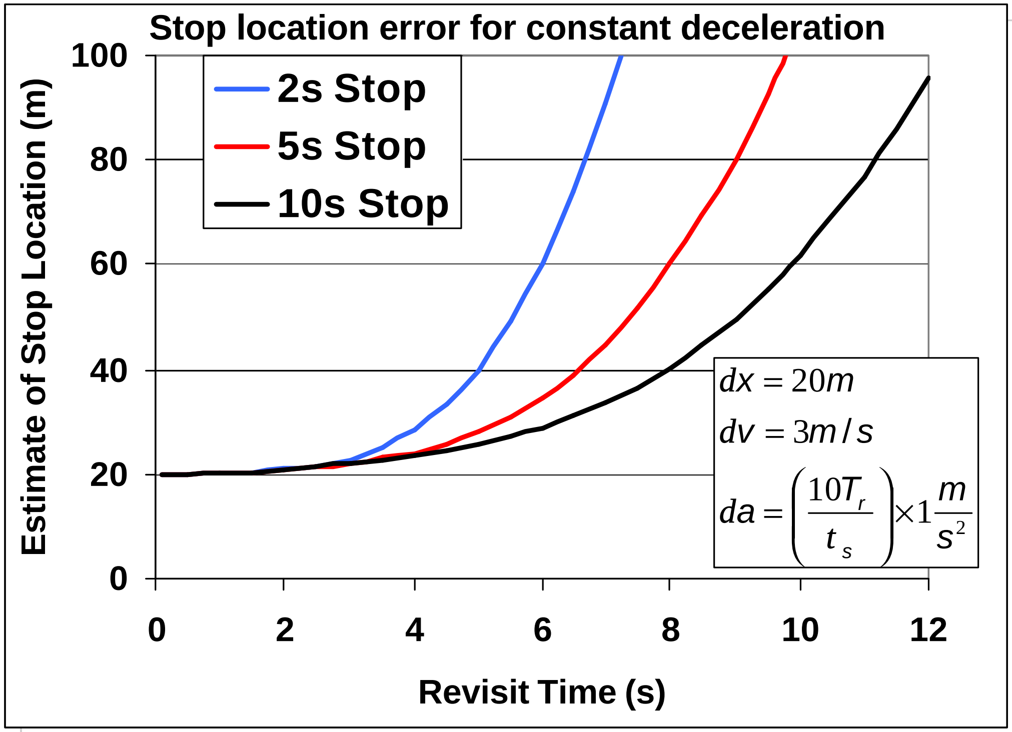
- Two separable problems:
  - Absolute bias errors with respect to geo-spatial reference frame
  - Relative bias or "gridlocking" is the relative errors between different assets
- Mitigation approaches:
  - Open-loop reduction of relative and absolute sensor errors
    - Better sensor platform navigation
    - Better initial sensor calibration
    - Operational calibration of sensor upon deployment
  - Tracker-based reduction of relative errors
    - Iterative tracker bias estimation removes relative biases if basic errors are small enough to allow reliable association
  - Close-loop reference-based bias removal with fixed reference points
    - Registered SAR reference imagery
    - Georegistered "stationary movers" (e.g. rotators)
    - Unattended ground sensors

Resource Requirements During Weapon Fly Out

- General premise: Two sensors and high revisit rate only required during final 5 -10 seconds before impact for optimal track accuracy.
- But what happens if the target stops during weapon fly out?
- Probably will not have sufficient time for SAR image after weapon launch
- GMTI, with sufficiently high revisit rate to estimate deceleration, may provide best stopped position estimate
- Hence, AMSTE may need to sustain two sensors with high revisit during entire weapon fly out

Time Required for SAR Image

	ISR	F15
Tasking	30	0
Integration	30	20
Processing + IA	20	5
Response IFTU	10	5
Total Time	90 s	30 s



Weapons Overview

- Weapon acceleration advantage gives near zero target escape capability
- Weapon guidance methods analysis
  - Weapon data link (WDL) is required against moving target
  - Desire few seconds in-flight targeting update (IFTU) latency
  - Require modifications to existing guidance algorithms
    - Both pursuit and proportional navigation studied yield acceptable performance
    - Main challenges are weapon time to go and height above terrain errors
- Terminal seekers can help overcome tracking errors
  - IR seeker are limited by low clouds, fog, and smoke
  - Handoff from radar eases burden on seeker
  - RF seekers could be most robust solution

Existing weapons with WDL modification should suffice

Endgame Insights

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- Moving targets require mutual sensing from at least two GMTI sensors with good angular separation and high revisit rates
  - Terrain can seriously impact availability of standoff sensors.
- Penetrating sensor could substitute for ISR endgame targeting
  - Dedicated sensor
  - Mitigates effects of terrain masking.
- Track error is more significant than weapon guidance error.
- Uncorrelated biases between measurement and delivery system unknown and potentially very important.
- High GMTI revisit rate during weapon flyout may improve performance against stopping targets.
- Existing weapons will work with minor modifications.

Required endgame accuracies appear feasible

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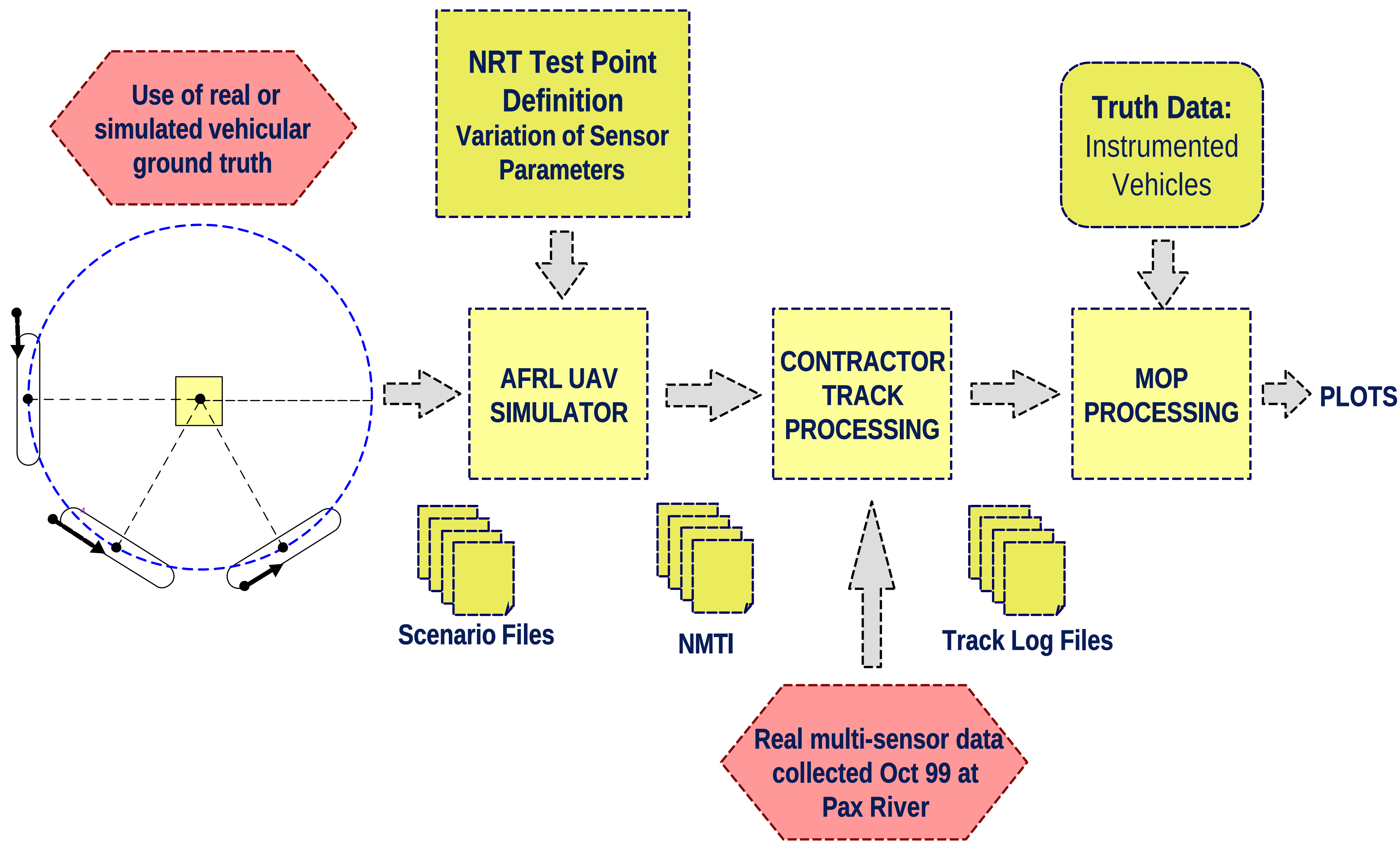
NRT1 and Pax River Lessons Learned

- Background
- Accuracy
- Latency
- Sensor Resources
- Biases
- Maps
- Target Mobility

Tracker Experiments



Tracking Experiments

Special Projects Office

- Non-Real Time Experiment 1 (NRT1) - completed
  - NRT1: Holloman AFB real vehicle motion data
    - Assess track accuracy versus number of sensor platforms and sensor performance
  - Objective: Track accuracy with multiple GMTI sensors
- Non-Real Time Experiment 2 (NRT2) - underway
  - PFCT Experiment NRT2a: Simulated Kosovo Scenario
    - Assess track continuity versus target density using simulated movements and data
  - PFCT Experiment NRT2b: ASCIET
    - Assess track continuity with synthetic data based on GPS collections during Ft. Stewart C^4I exercises
  - PFCT Experiment NRT2c: Pax River Data
    - Assess track accuracy with real GMTI data from multiple platforms
  - Objectives:
    - Track maintenance (NRT2a and NRT2b)
    - Assessing error budget on real data

Data Collections

- Data Collection #1: Holloman precision ground truth data
  - Validate quality of ground truthing (< 1 m position accuracy, 2 Hz sampling)
  - Data collected on 28 vehicle motion vignettes (~ 40 minutes each)
  - Data was used in PFCT Experiment 1
- Data Collection #2: Pax River Multiple-platform GMTI data
  - Simultaneous data collected from 3 GMTI sensors
    - 4th Gen - Northrop Grumman fighter radar surrogate
    - APY-6 - Northrop Grumman standoff radar surrogate
    - Lynx - Sandia Laboratory standoff radar surrogate
  - Data was used as part of PFCT Experiment NRT2c.

NRT1 Tracker Experiments
Values of Notional Sensors

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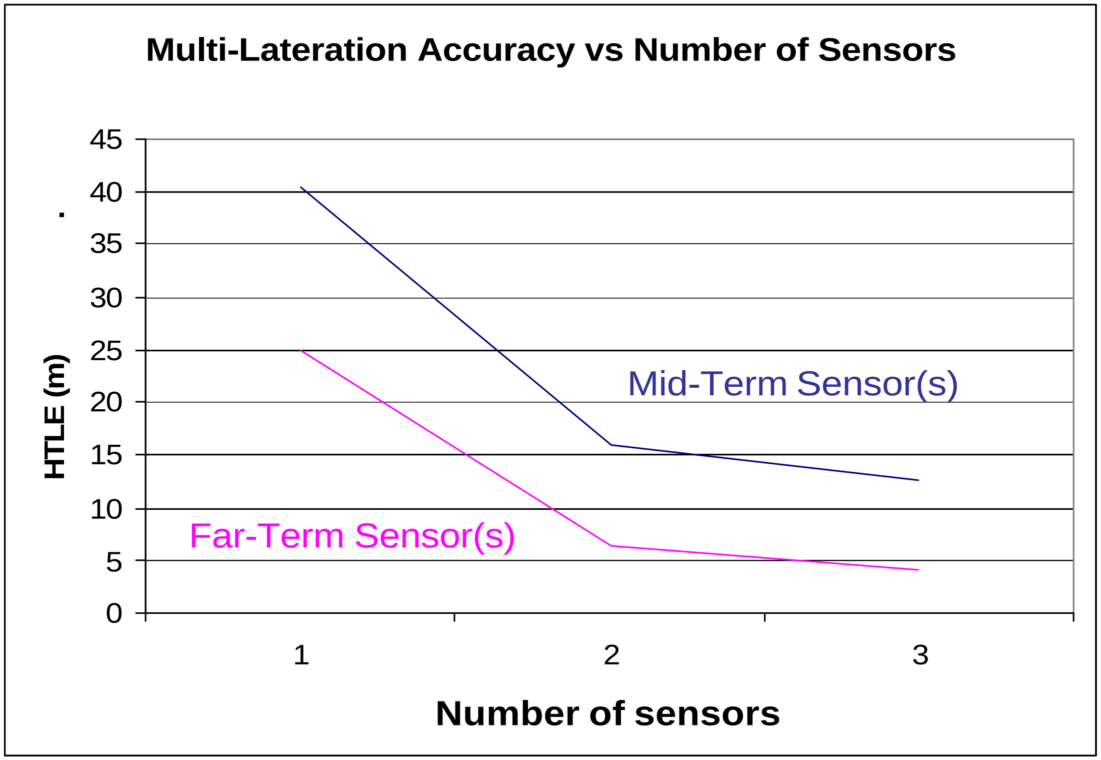
	Mid-Term	Far-Term
• Revisit interval (seconds):	3	1
• Baseline prediction time into future (seconds):	3	3
• Relative latency w.r.t. host platform (seconds):	2	2
• Baseline 1-σ range noise error (meters):	6	1
• Baseline 1-σ range bias error (meters):	6	2
• Time constant for range bias error (minutes):	10	10
• 1-σ range-rate noise error (meters/second):	1	0.3
• 1-σ platform navigation 3-D bias error (meters):	5	1
• Time constant for navigation 3-D bias error (minutes):	2	2
• 1-σ azimuthal noise error (radians):	0.001	0.001
• 1-σ azimuthal bias error (radians):	0	0
• MDV (meters/second):	2	1
• Pd:	0.9	0.9
• False Alarm Density:	0	0
• Range (kilometers):	150	150
• Altitude (feet):	30,000	30,000
• Duration of sensing interruption (minutes):	1	1
• Quality of road map data:	USGS*	USGS*
• Static-movers (unknown targets of opportunity)	5	5

(*<=Tiger)

Number of Sensors and Accuracy

- Multi-lateration improves target location error by > 50%
- Three sensors provide only marginal improvement over two
  - (3 sensors provide robustness against masking, MDV, platform turns)
- Expected mid- and far-term sensors yield <20 and <10m horizontal TLEs with 2-sensor multi-lateration

HTLE (m) = Horizontal Target Location Error (meters)



Results confirm benefits of multi-lateration with 2 sensors

Latency

- Total system (pipeline) latencies of 3 to 5 seconds degrade performance by ~25% to 50%
  – Results valid for notional sensor parameters
- Ability to handle out-of-sequence detections is critical
  – Otherwise, single sensor accuracies will result
- Latency linearly projects into target location error
  – Acceptable system latency is dependent upon total sensor tracking HTLE
  – < 3 seconds desirable

Short System Latencies Are Acceptable

Sensor Resources 1

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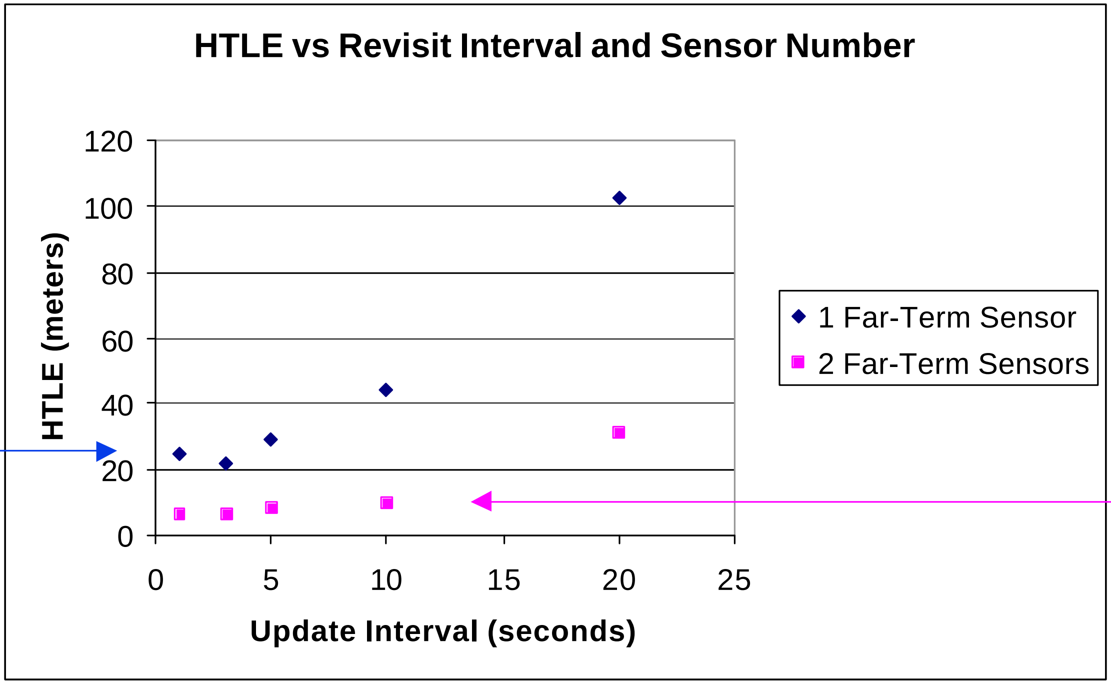
- Considerable sensor resource savings accrue from multi-lateration

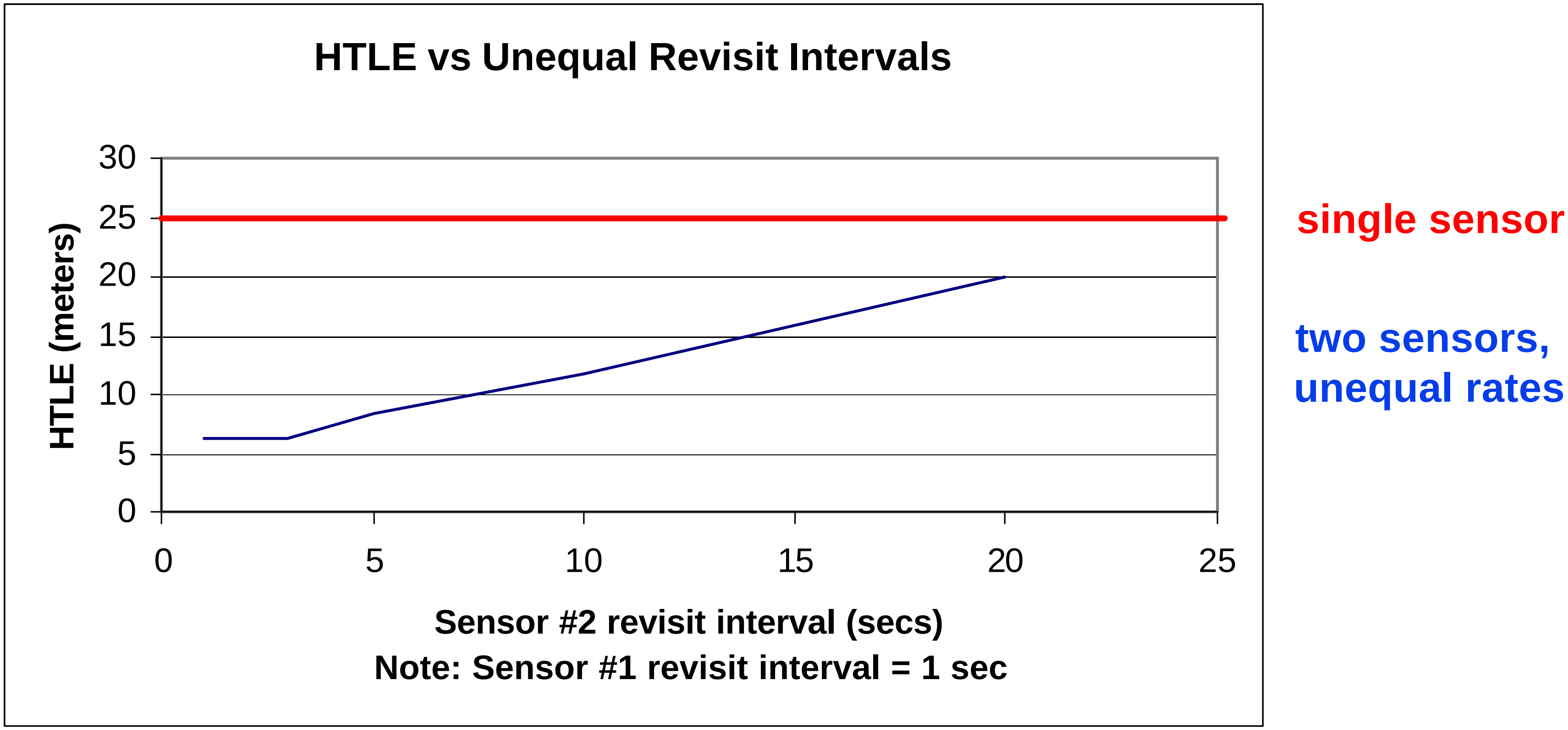
1 second update for one sensor gives ~25m error



10 second update per sensor yields ~10m error for 2 sensors

Revisit Rate Can Be Lowered by More Than 2X and Still Obtain Better Accuracy Than Single Sensor

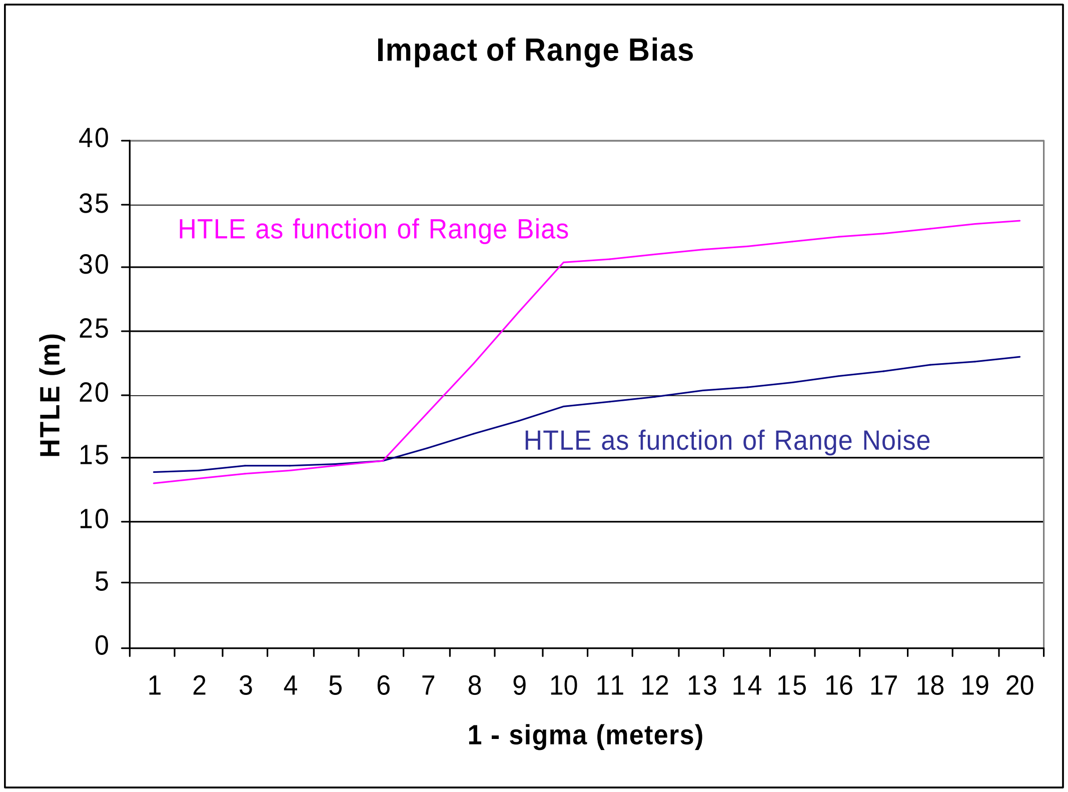
Sensor Resources 2



Even Less-Frequent 2nd-Sensor Updates Provide High Value

Biases 1

- Range bias mitigation is an important issue.



Range Bias Has More Impact Than Equivalent Range Noise

Biases 2

- Short-range calibration does not seem to be an issue based on Pax River data collection
  – whether that carries to long-range is an open question
- Targets-of-opportunity gridlock has not demonstrated real utility
  – Surveyed stat-movers works for gridlock
- NRT1 used a first-order Gauss-Markov model of bias dynamics
  – the time constant for bias changes was an engineering guess
  – magnitude of bias also an engineering judgment
  – biases for long range measurement need more study

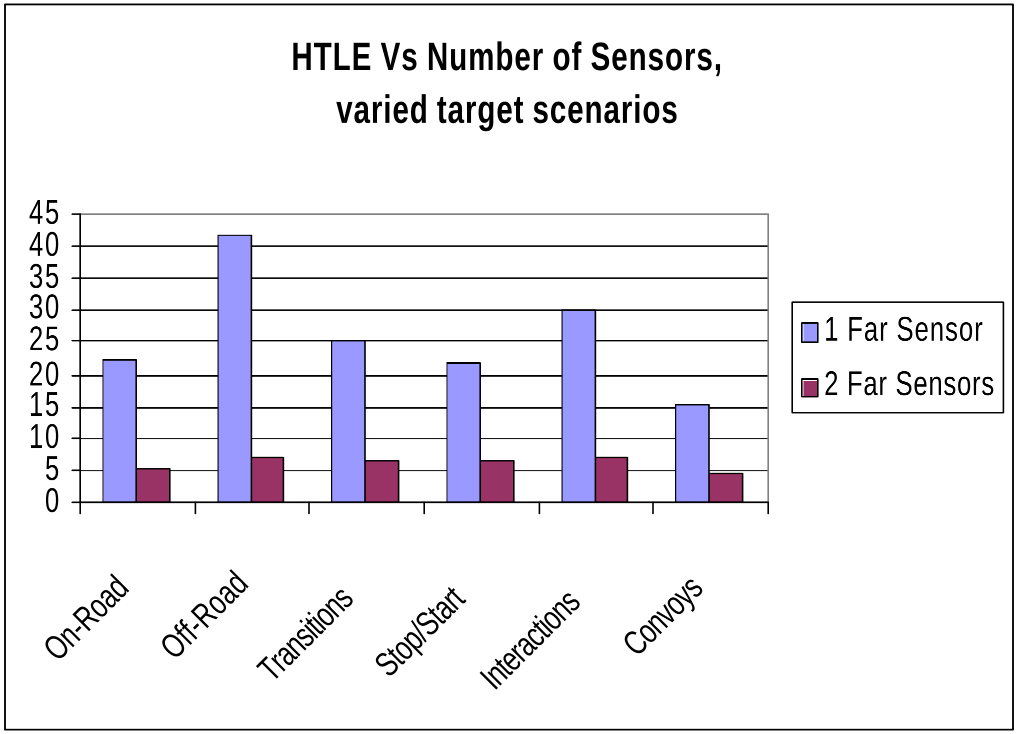
Impact of Digital Road Maps

- Road map information of Tiger-quality* has been shown to improve tracking performance in some cases

- Impact on track maintenance an open issue

* Census Bureau modifications of USGS, ≤40 m accuracy

Target Mobility



Multi-Lateration Is Robust to All Types of Target Motions

NRT2 Comments

- PFCT Contractors are currently working with NRT2 data
- Early results show
  - expected accuracies with real data (NRT2c Pax River)
  - good agreement between real data and expected error budgets
  - challenges doing purely kinematic association during maintenance tracking
    - with large numbers of close target encounters
    - with targets stopping for long periods in move-stop-move activity
  - features without aspect dependence offer better prospects

PFCT Summary

- Analysis of precision fire control tracking showed feasibility of AMSTE mission
  - HTLEs supported
  - reasonable revisit rates
  - resource requirements are reasonable.
- Precision fire control to support HTLEs of <10m is enabled by:
  - two or more GMTI sensors
  - weapon data link
  - sensor accuracy improvement
  - sensor bias removal.
- Long term track maintenance remains a significant challenge
  - may be improved if feature aided tracking successful.

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Phase I Lessons Learned

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- AMSTE is a systems approach that requires
  - Effective transitions through the kill chain
  - Coordination and availability of GMTI and other modes
  - Tight response timeline.
- Performance limitations are reduced as more netted sensors are able to contribute to engagement.
- Maintaining track may be the most difficult technical challenge.
- Required endgame accuracies appear feasible with netted sensors.
- AMSTE can be implemented with data link modification to existing weapons.

Technical Challenges

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- Effective transitions: Advance the target through the kill chain
  - transition from nomination requires a quick change in the operational tempo for track maintenance and locking in the common target
  - handoff for endgame likely requires transferring target maintenance responsibility and common target identification
- Response time:
  - limited by BM/C3 decision cycle; it sets the requirement for time in track and resource loading
- Track maintenance: holding track in presence of
  - other traffic
  - move-stop-move cycles
- Endgame precision:
  - orchestration and geo-registration of multiple sensors and weapons
  - dynamic allocation of sensor and weapon data links
  - sensor resource loading

AMSTE II
Bidders Briefing

Special Projects Office

9:00 am	Welcome and Administrative Comments	
9:15 am	DARPA/SPO Overview	Stephen Welby, DARPA
9:30 am	AMSTE Introduction	Stephen Welby, DARPA
Break		
10:30 am	AMSTE I Program Elements	Jon Jones, AFRL
10:40 am	AMSTE I Results	Robert Enders, MITRE
11:40 am	AFRL Capabilities and Data	Jon Jones, AFRL
12:00 pm	Moving Target Features	Rob Williams, AFRL
Lunch		
1:30 pm	AMSTE II Description	Stephen Welby, DARPA
Break		
2:45 pm	Proposal/Contract Requirements	Jon Jones, AFRL
3:15 pm	Closing Comments	Stephen Welby, DARPA

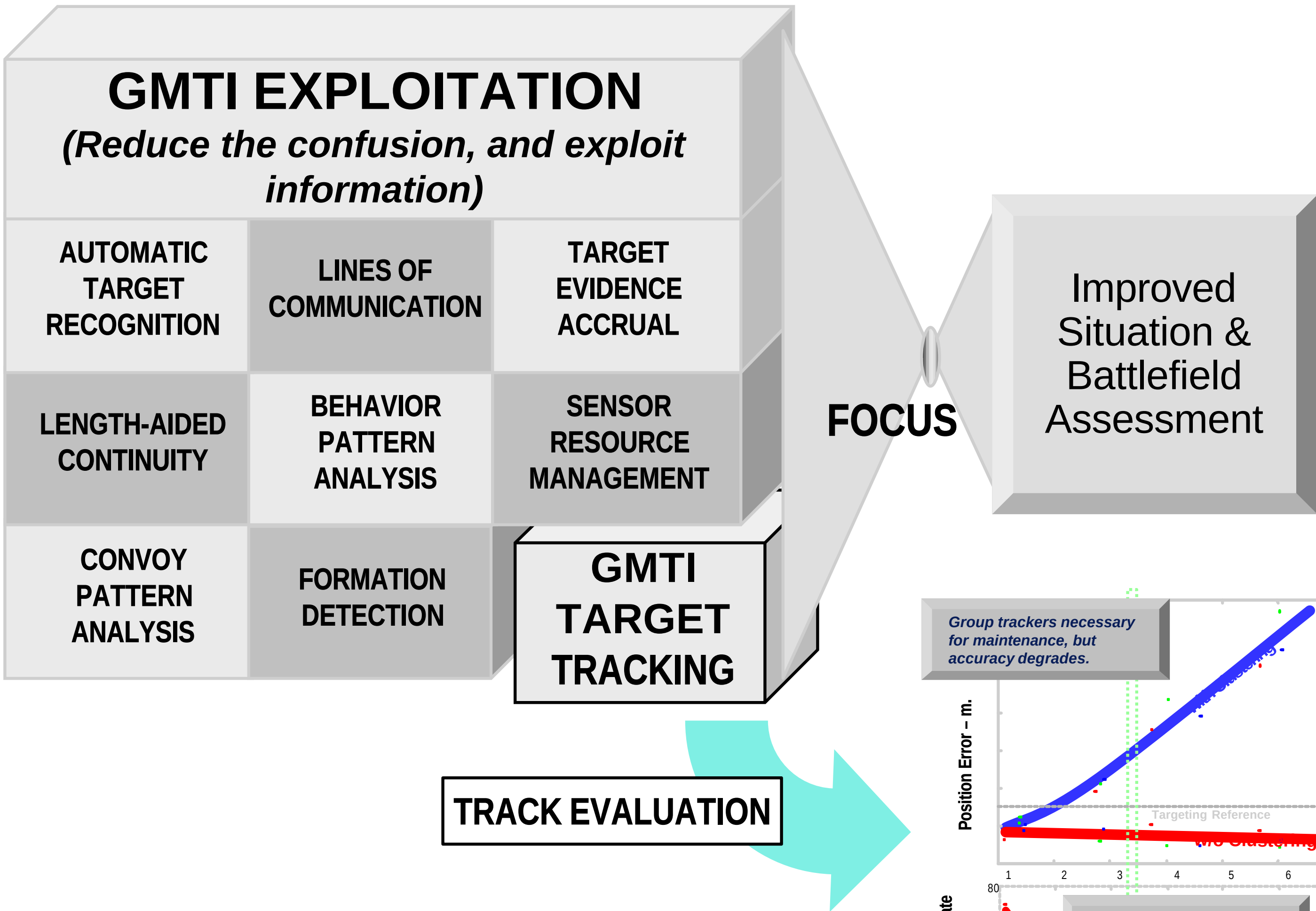
AFRL/IF - Rome Capabilities and Data

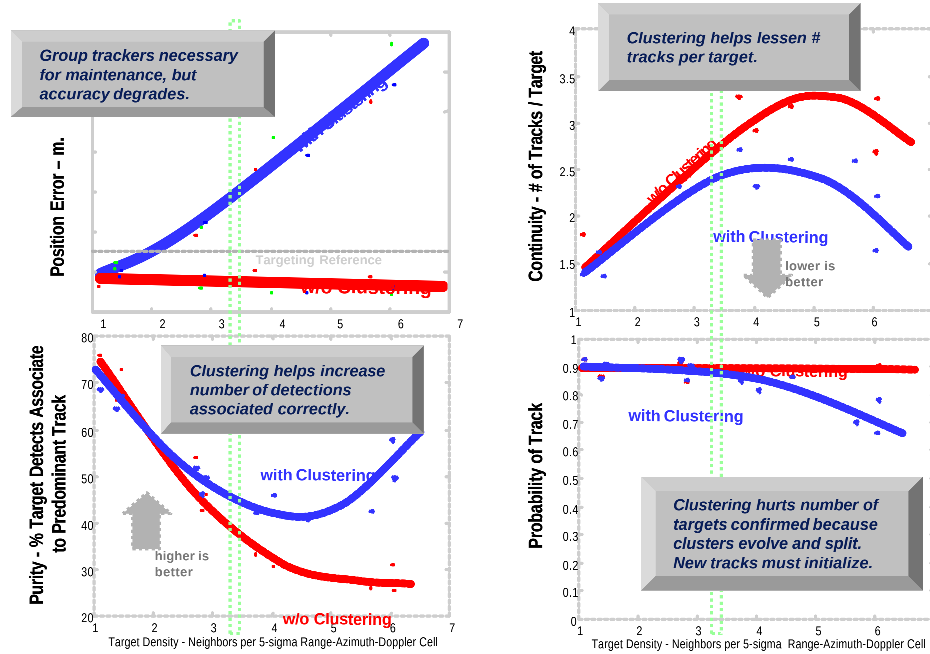
Jon Jones, AFRL

GMTI at AFRL

- GMTI Exploitation Evaluation
  - Legacy programs have developed AFRL's understanding of the process.
- Databases
  - Simulated
  - Operational
  - MTE, AMSTE, DDB

Moving Target Exploitation (MTE) Program



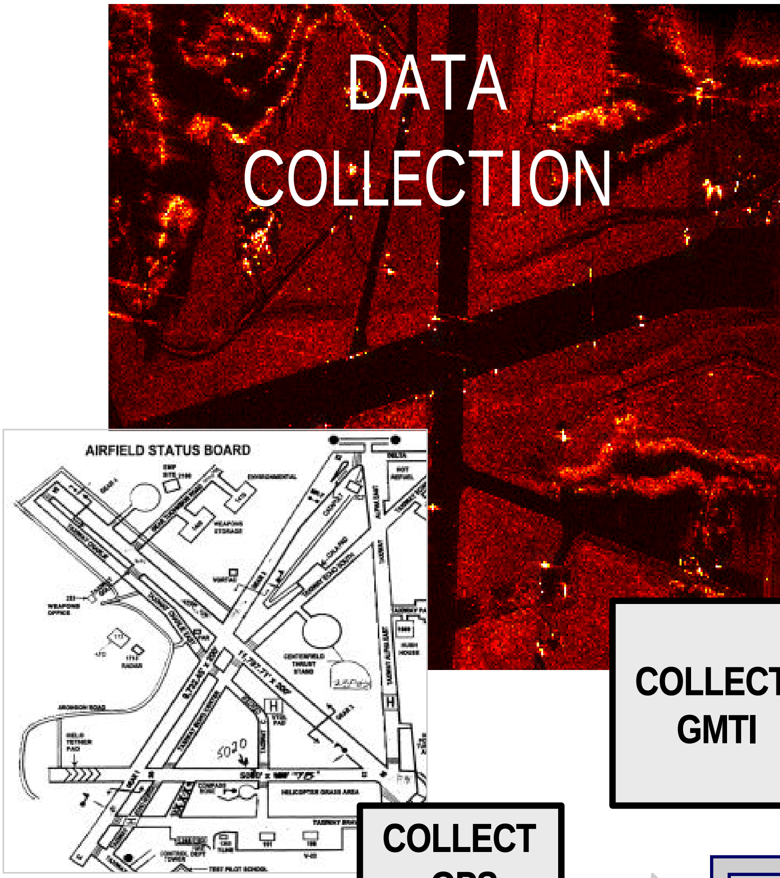


Situation Assessment Mission – Short Tracks Improve Battlespace Picture

AFRL GMTI Database

- GMTI Data Sources
  - Type I: Real Data
  - Type II: Synthetic Data
  - Type III: Simulated Data

Type I: Real Data Process



Collect ALL Data and output common format.

COLLECT Platform Truth

COLLECT GMTI

COLLECT GPS Ground Truth

Truth

NMTI

Truth Association Necessary

Roads & Terrain

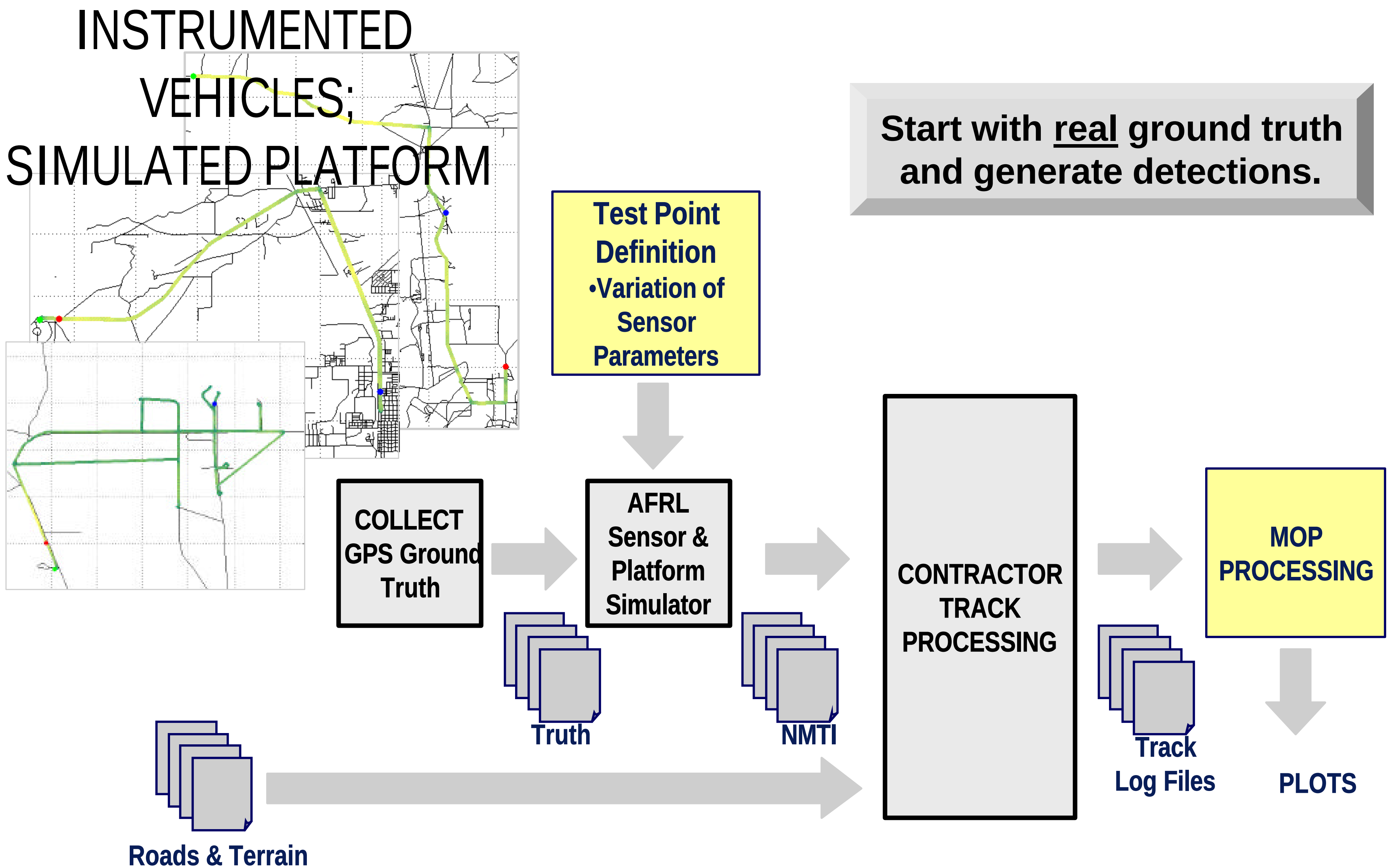
CONTRACTOR TRACK PROCESSING

Track Log Files

MOP PROCESSING

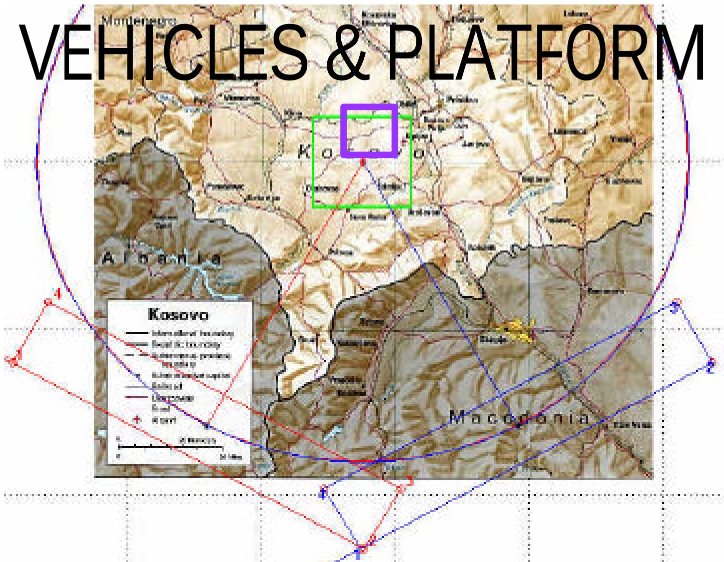
PLOTS

Type II: Synthetic Data Process



Type III: Simulated Data Process

SIMULATED VEHICLES & PLATFORM



Develop simulated ground truth and generate detections.

Test Point Definition
- **Variation of Sensor Parameters**

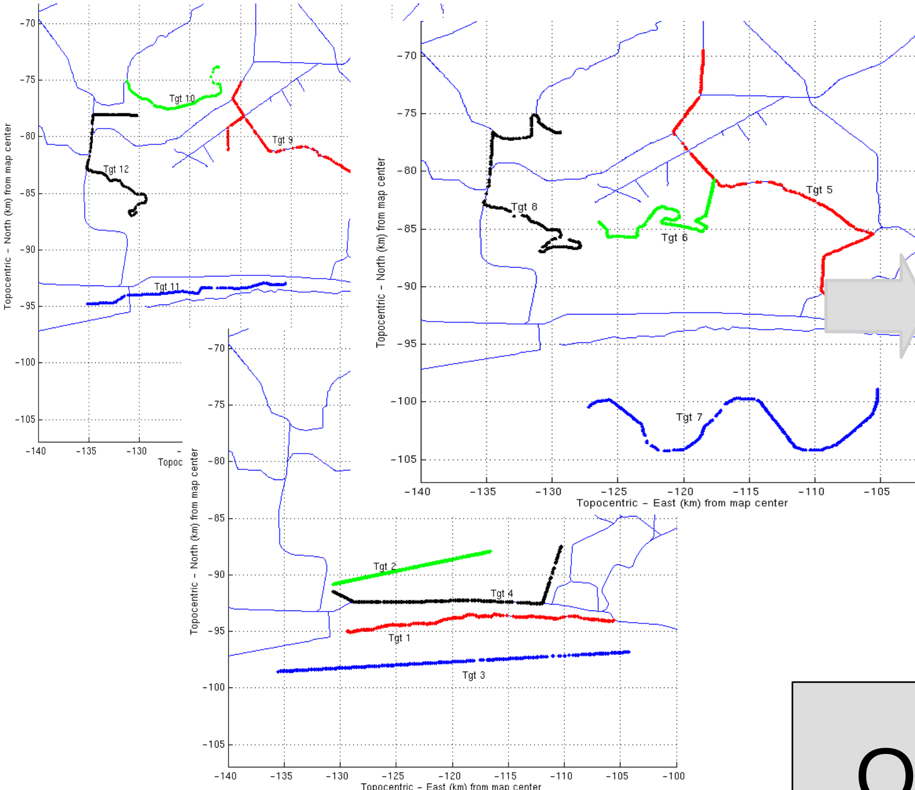
Three main uses:
- Exploring performance extremes,
- Testing to reduce risk,
- Analysis under controlled environment.

Create GPS Ground Truth → **Truth** → **AFRL Sensor & Platform Simulator** → **NMTI** → **CONTRACTOR TRACK PROCESSING** → **Track Log Files** → **MOP PROCESSING** → **PLOTS**

Roads & Terrain → **CONTRACTOR TRACK PROCESSING**

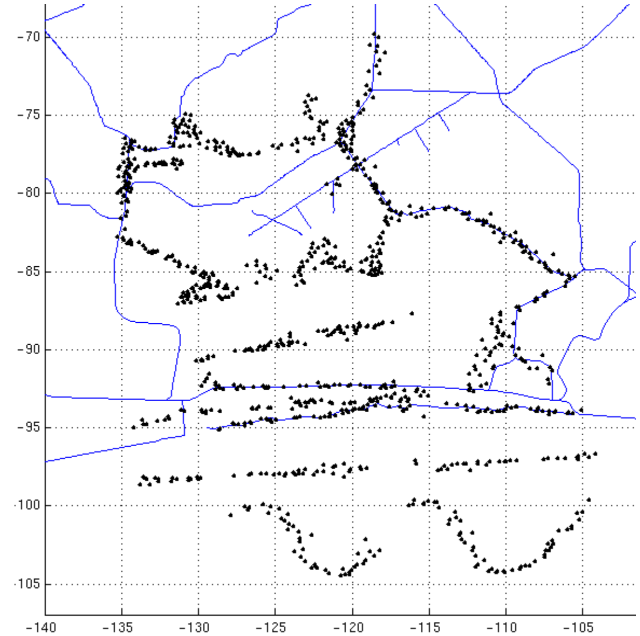
UAV Radar Model

INPUT - TRUTH



Radar Model

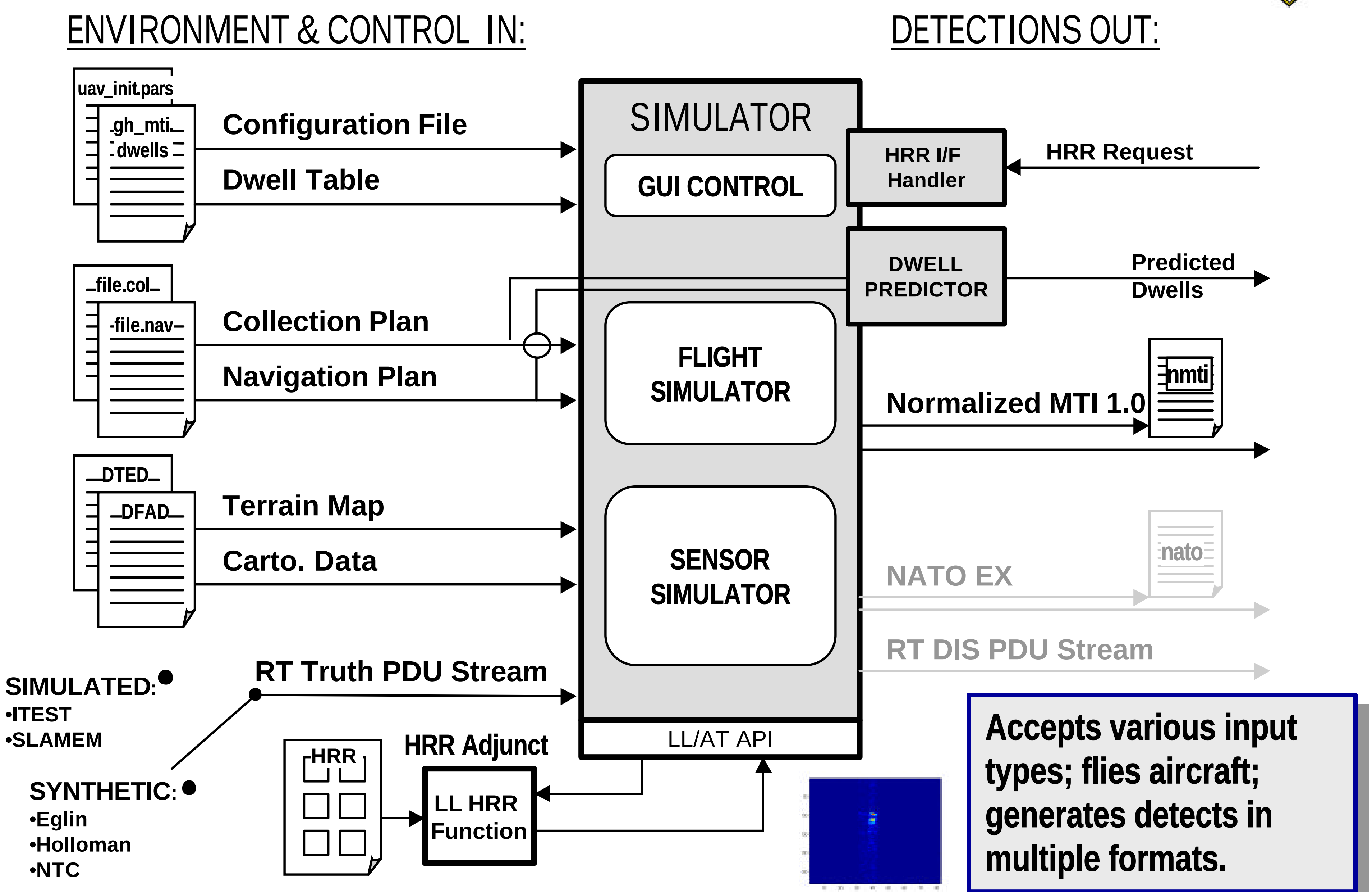
OUTPUT - DETECTIONS



OUTPUT FORMATS:

- Normalized GMTI (NMTI)
- NATO EX
- Streamed DIS PDUs
- Common GMTI (CGMTI) - planned

UAVSIM Top-Level Interfaces

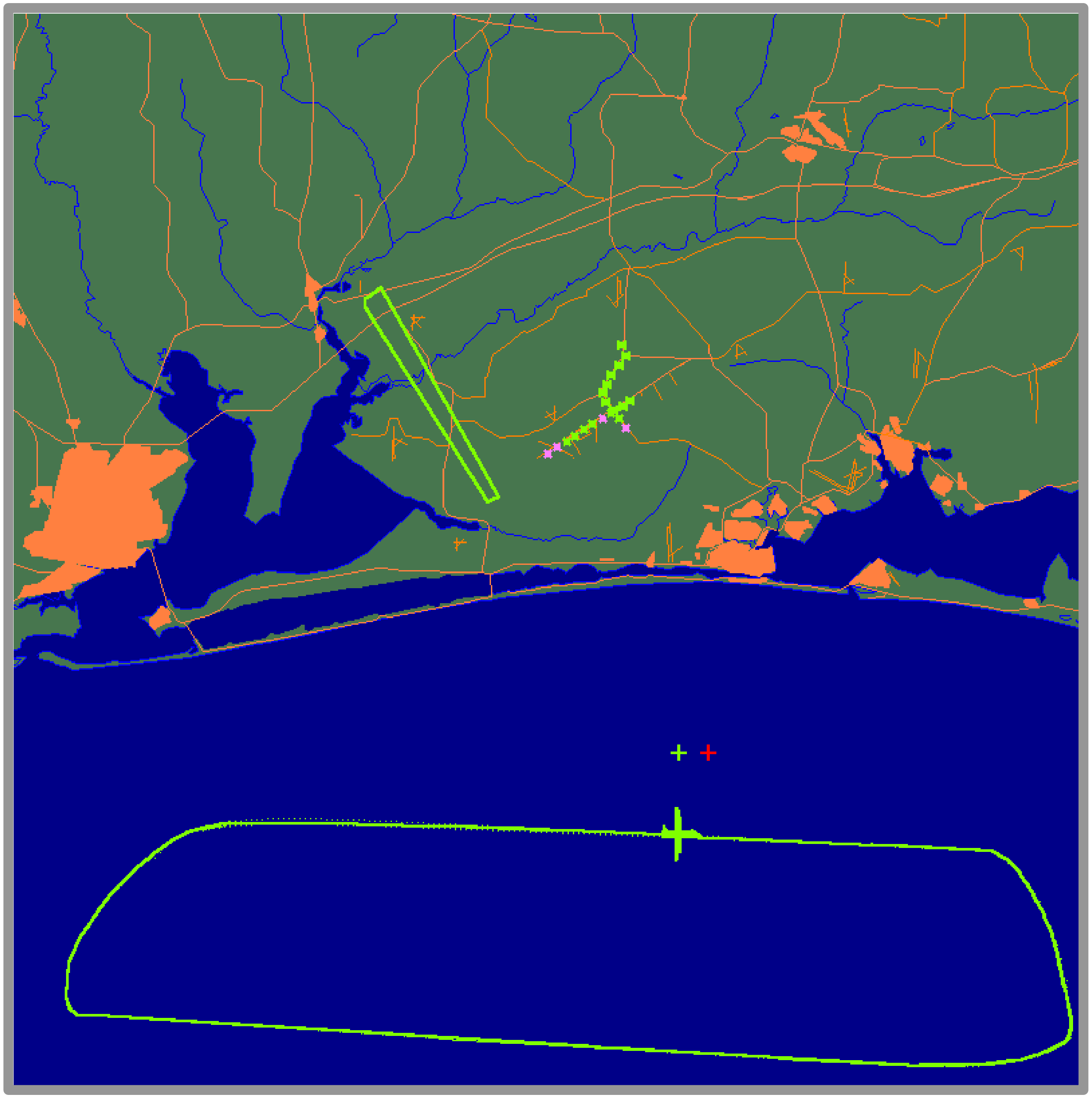


Target Modeling

- ITEST
  - Scripted scenarios
  - Some Limitations: Constant velocity, instant stop/start
  - Laborious
- Ground Vehicle Simulator (GVS; an evolution of SLAMEM)
  - Scripted & random
  - Automated vehicle interaction
  - More realistic motion (accel/decel, random speed fluctuations,…)
- SLAMEM
  - AMSTE I model had instant stop/start.
- MODSAF
  - Force engagement; unscripted; unpredictable

Generate up to thousands of targets in any locale

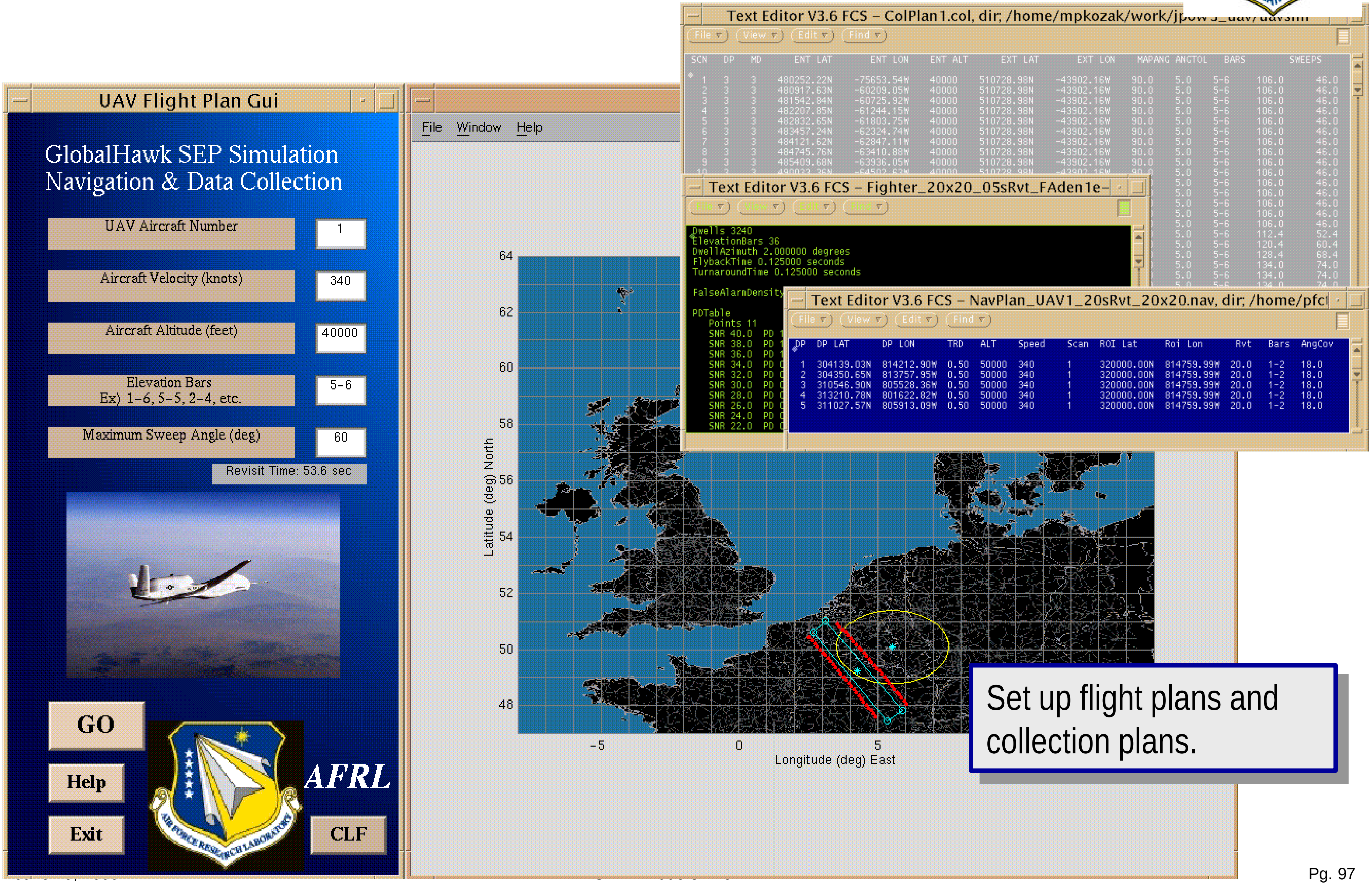
Sensor & Flight Model (UAVSIM)



GMTI GENERATOR

- Parametric Radar Model
- Terrain Obscured
- Min. Detect. Velocity
- Dwell-based
- Overlapping El. Bars
- Gaussian Loc. Errors
- DIS-based I/O

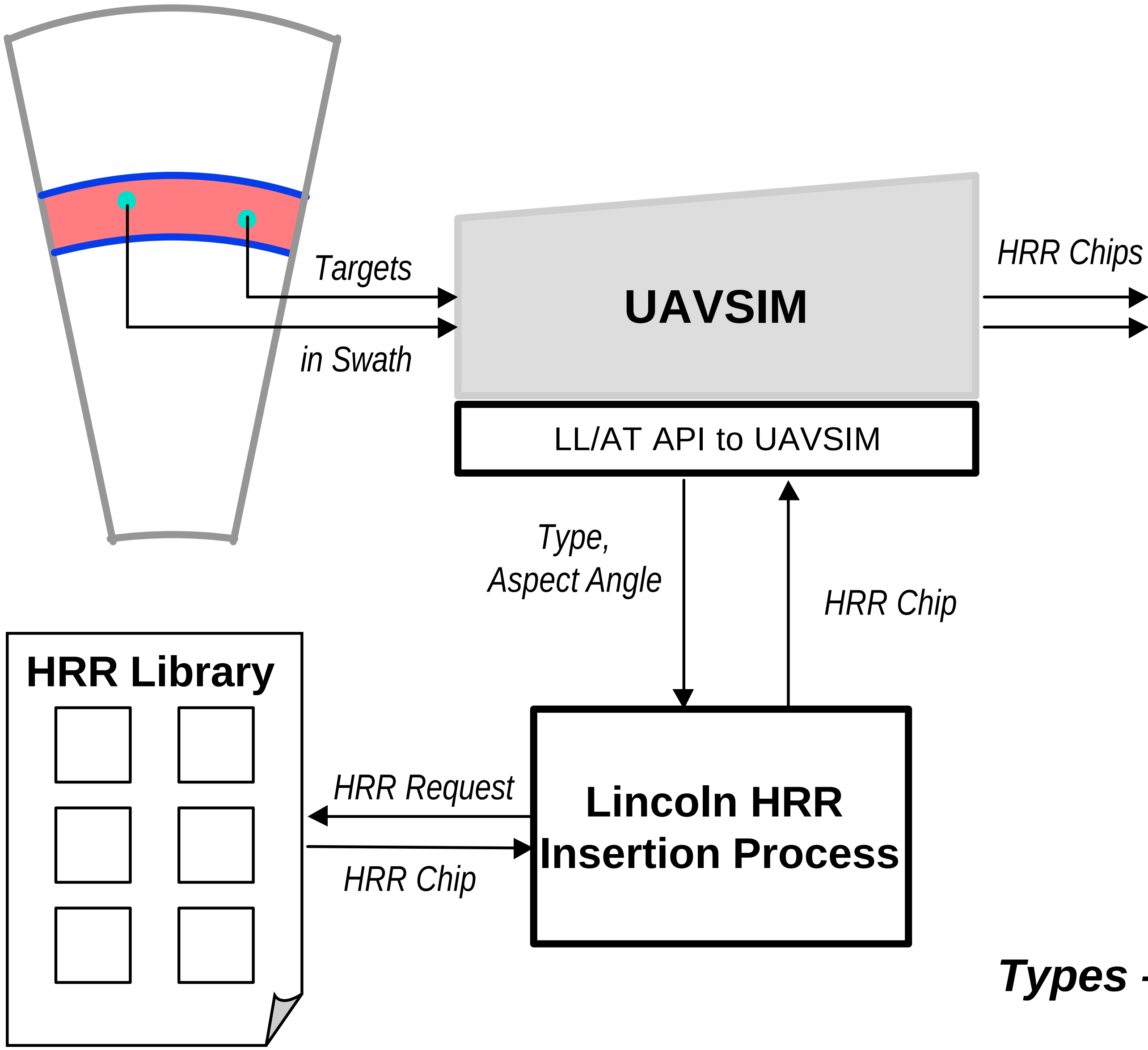
UAVSIM Navigation and Data Collection Ground Station Planning Utility

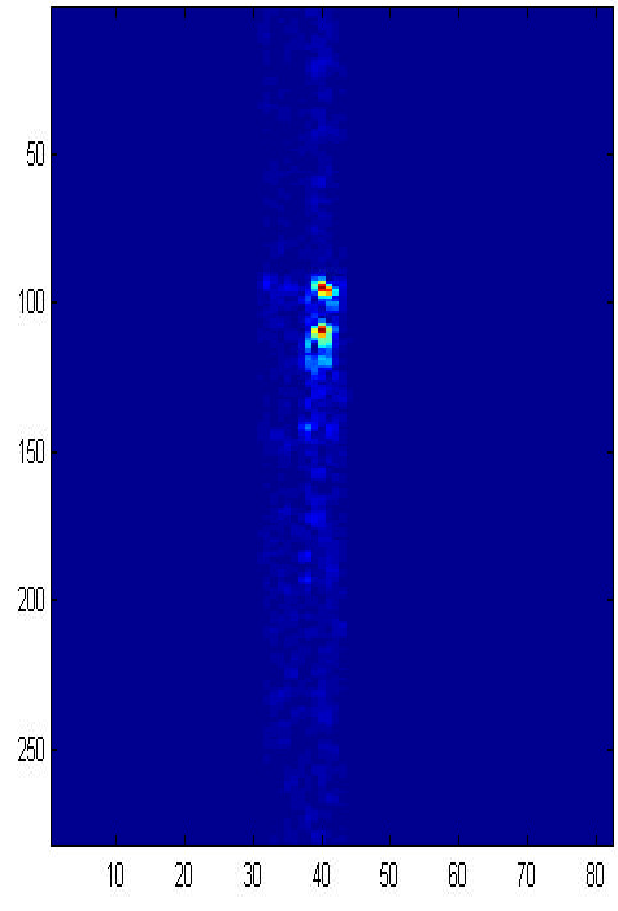


Set up flight plans and collection plans.

HRR Chip Insertion

- Simulator can insert chips into the NMTI record

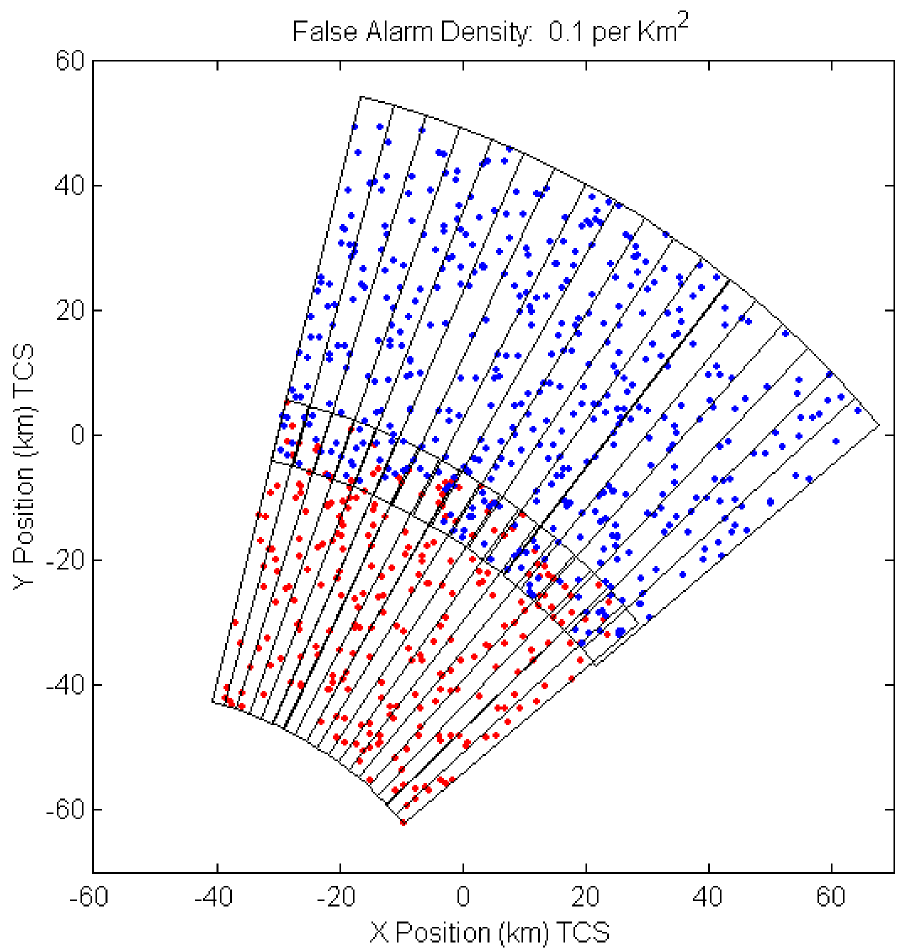


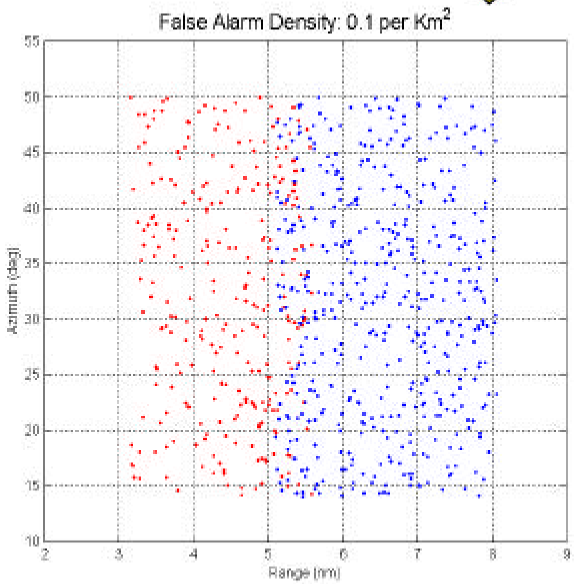


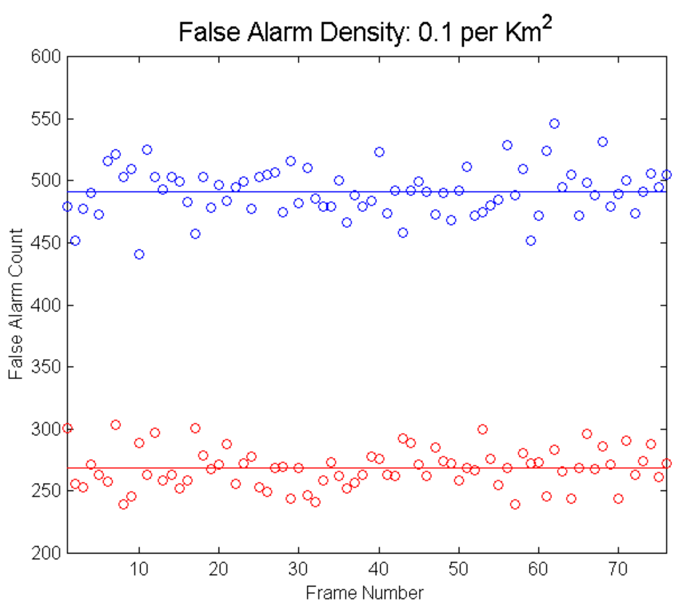
Types – Tank, Truck, TEL, Helo

False Alarms Generator

- Number of False Alarms in each bar is Poisson.
- Uniform Distributions in Range, Azimuth, and Velocity XYZ components. Velocity > MDV.
- Feature data is 0 mean Gaussian w/ s_W=2*sqrt(2)







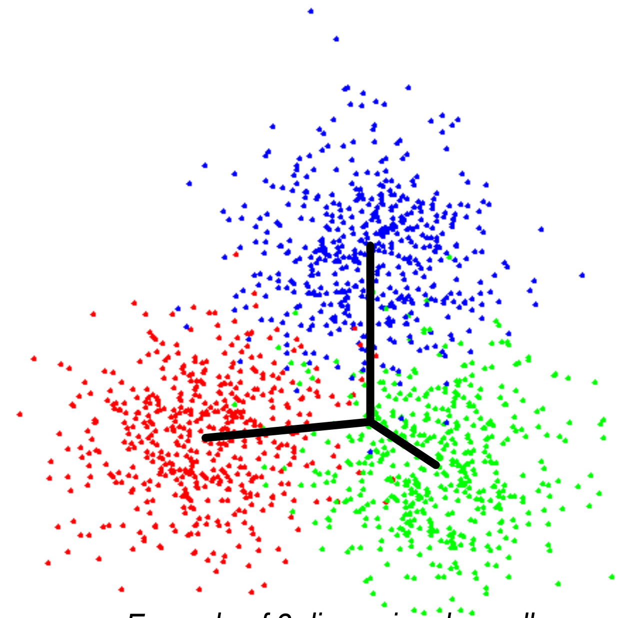
Abstract Feature Generator

K-factor : $$K = \frac{\sqrt{2}}{\sqrt{s_v^2 + s_w^2}}$$

Assume no "within" class variation, $s_v^2 = 0$

and $s_{w_1} = s_{w_2} = \ldots = s_{w_N}$

Then, $$s_w = \frac{\sqrt{2}}{K}$$



Example of 3 dimensional equally separated vectors with K=4.

	K	P_{CA}	s_w
None	0.0	0.50	-
Low (Kf1)	1.0	0.69	1.4141
Med (Kf2)	2.0	0.84	0.7071
High(Kf4)	4.0	0.98	0.3536

GMTI Data Available

- AFRL offers data for online catalog.
- Simulated & Synthetic
  - MTE, AMSTE, AFRL
- DARPA Data Collections
  - MTE, AMSTE subset, DDB
- Operational
  - June 1999 Kosovo Missions
- Truth and Platform Data provided when available

Operational data provides reference point for scenario design

NRT1 Test Summary

	DATA TYPE	LOCATION	#TEST POINTS	#NMTI FILES	#TARGETS	DURATION (min)	PARAMETER VARIATIONS											
							SENSOR TYPE	# SENSORS (2)	REVISIT RATE (3/1)	AZIMUTH NOISE (.001)	RANGE NOISE (6/1)	AZIMUTH BIASTC (0/0)	RANGE BIAS (6/2,10/10)	NAVIGATION (5/1,2/2)	#STAT MOVERS (5)	MAP ACCURACY	MOBILITY	LATENCY
NRT1A	SYN	Holloman	65	65	4	30	✓	✓	✓									
NRT1B	SYN	Holloman	105	64	4	30	✓	✓		✓	✓		✓	✓				
NRT1C	SYN	Holloman	115	24	10/4	30	✓	✓							✓	✓	✓	
NRT1D	SYN	Holloman	100	72	12	30	✓	✓	✓			✓			✓		✓	✓
EDS – e1	SIM	Eglin	-	36	12	30												
EDS – e2	SYN	Eglin	-	2	8	60												
EDS – e3	SIM	Kosovo	-	2	10	60												
EDS – e4	SYN	Holloman	-	4	3	30												
EDS – e5	SYN	Holloman	-	4	3	30												

NRT 2 PFCT Data

Experiment Name	Number of Files	Total Size	Comment
Kosovo EDS 1 of 3	22	450 Mb	30 x 30 ROI, 10 to 510 Targets
Kosovo EDS 1 of 3	22	550 Mb	10 x 10 ROI, 10 to 110 Targets
Kosovo EDS 2 of 3	46	1200 Mb	10 x 10 ROI, 10 to 110 Targets Truth Height Problem Corrected
Kosovo NRT 1 of 2	46	1200 Mb	10 x 10 ROI, 10 to 110 Targets Truth Height Problem Corrected
Kosovo NRT 2 of 2 (Supplemental)	20	500 Mb	10 x 10 ROI, 10 to 110 Targets Added High K and High K No Cosine
Ft.Stewart EDS 1 of 2	20	260 Mb	20 x 20 ROI, 72 Targets
Ft.Stewart EDS 2 0f 2	26	320 Mb	20 x 20 ROI, 72 Targets New Data High K and High K No Cosine
Ft.Stewart NRT 1 of 1	26	400 Mb	20 x 20 ROI, 87 Targets New Data High K and High K No Cosine

File sizes are an order of magnitude larger than NRT1 because of addition of false alarms ~35/frame, feature vectors added to every MTI report, and 2 hour scenarios versus 30 minutes

Supporting Infrastructure

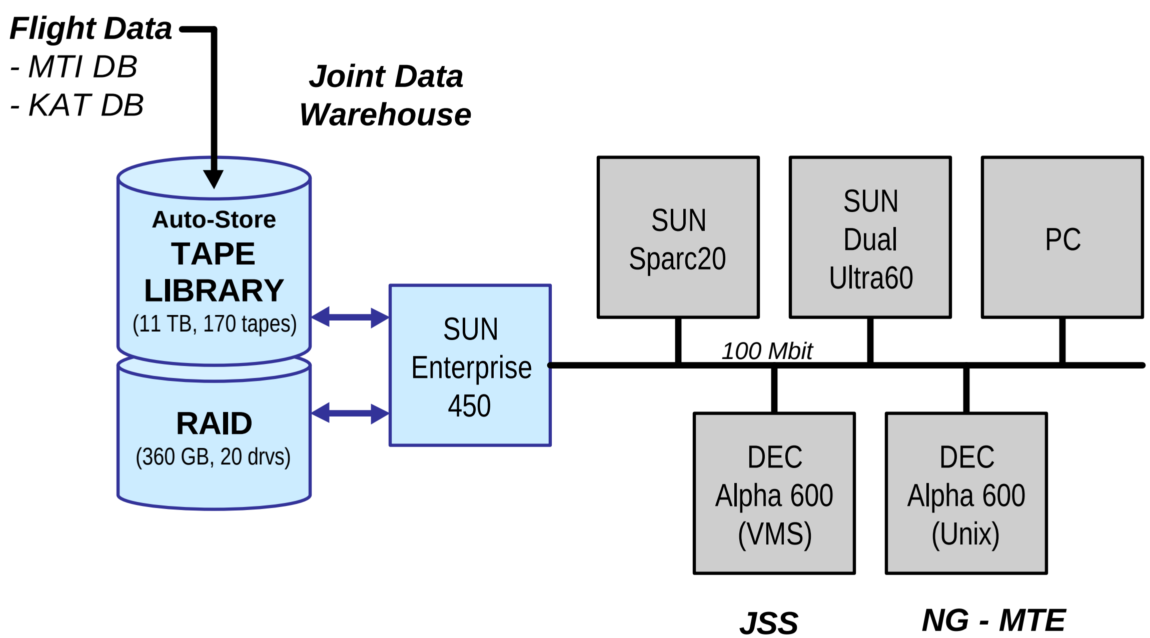
- Coordinate Definitions – clear understanding necessary
  - Geodetic vs. Geocentric vs. Topocentric.
  - Geoid & Ellipsoid definitions.
  - Adjunct briefing available.
- Conversion & I/O Libraries – provides consistency
  - Coordinate conversions.
  - Format readers & writers (e.g. NMTI).
- Interface Control Documents – available as reference
  - NMTI, NRT, TDIF, AFRLlog
- Utilities – non-proprietary aids
  - Display tools - FusionMap.
  - Matlab toolbox for conversion and file I/O.
  - Map & Terrain Databases.

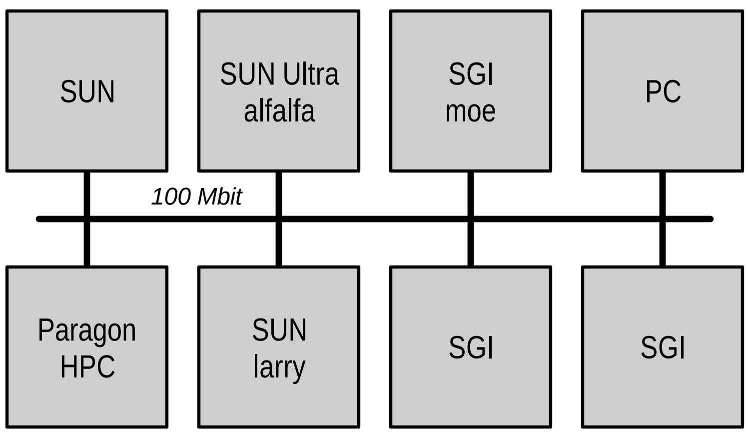
Useful to remove risk in system integration & test phases

AFRL Laboratory Facility

CLASSIFIED NETWORK #1:

- *Data Archive*
- *Joint STARS Sim. - RDO.*
- *KAT Track*
- *MOPS Tool*
- *CGSLite*
- *MTIX*





UNCLASSIFIED NETWORK #2:

- *OBIX - Multisensor Fusion, Comm, & Res. Alloc. Sim.*
- *JSTARS - RDOLite*
- *Rivet Joint Sim.*
- *AWACS Sim.*
- *UAV Sim.*
- *Spaced-Based Radar Sim.*
- *MHT Track*
- *FusionMap*

AMSTE II
Bidders Briefing

Special Projects Office

9:00 am	Welcome and Administrative Comments	
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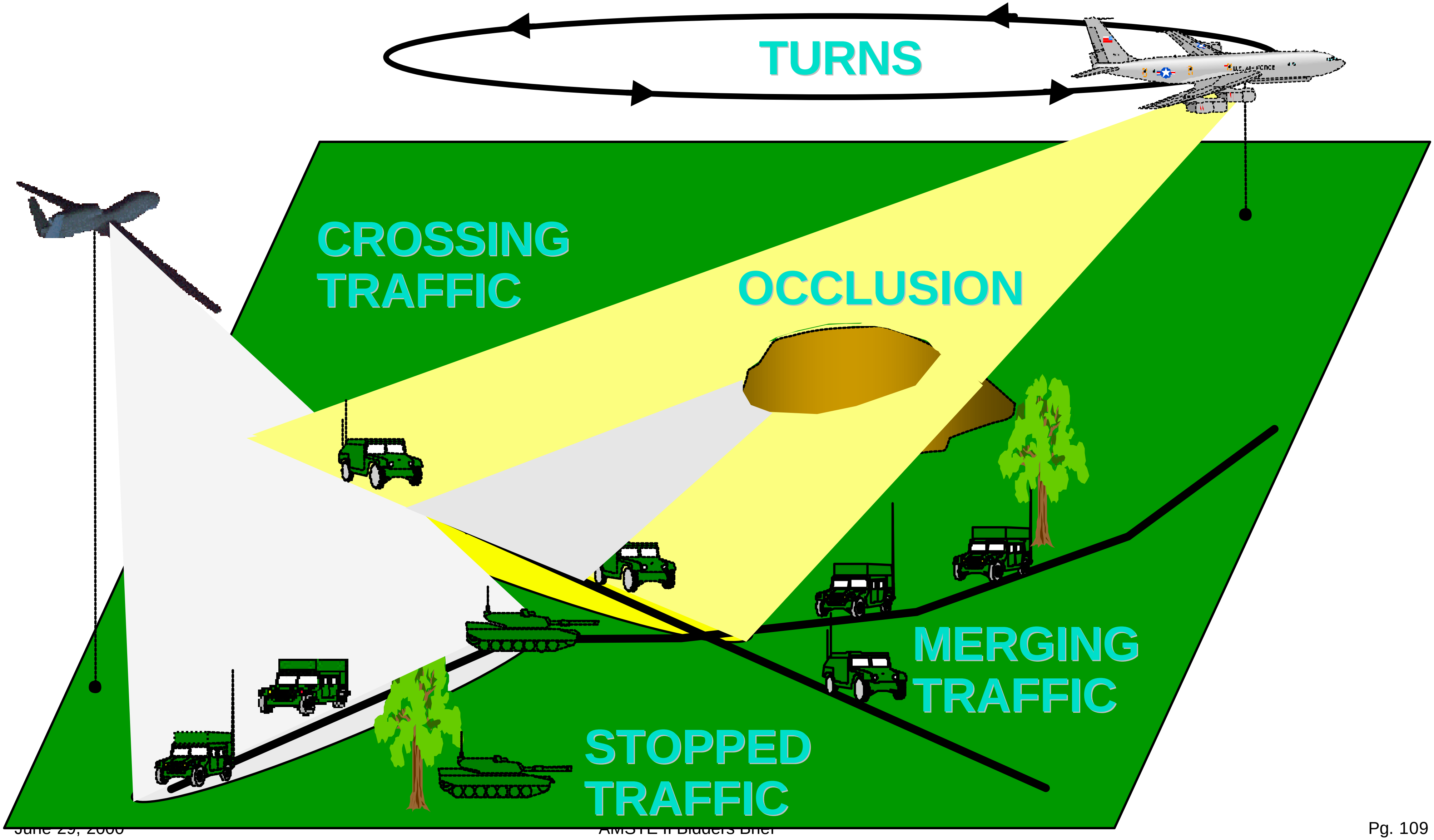
Moving Target Features for Tracking

Rob Williams, AFRL

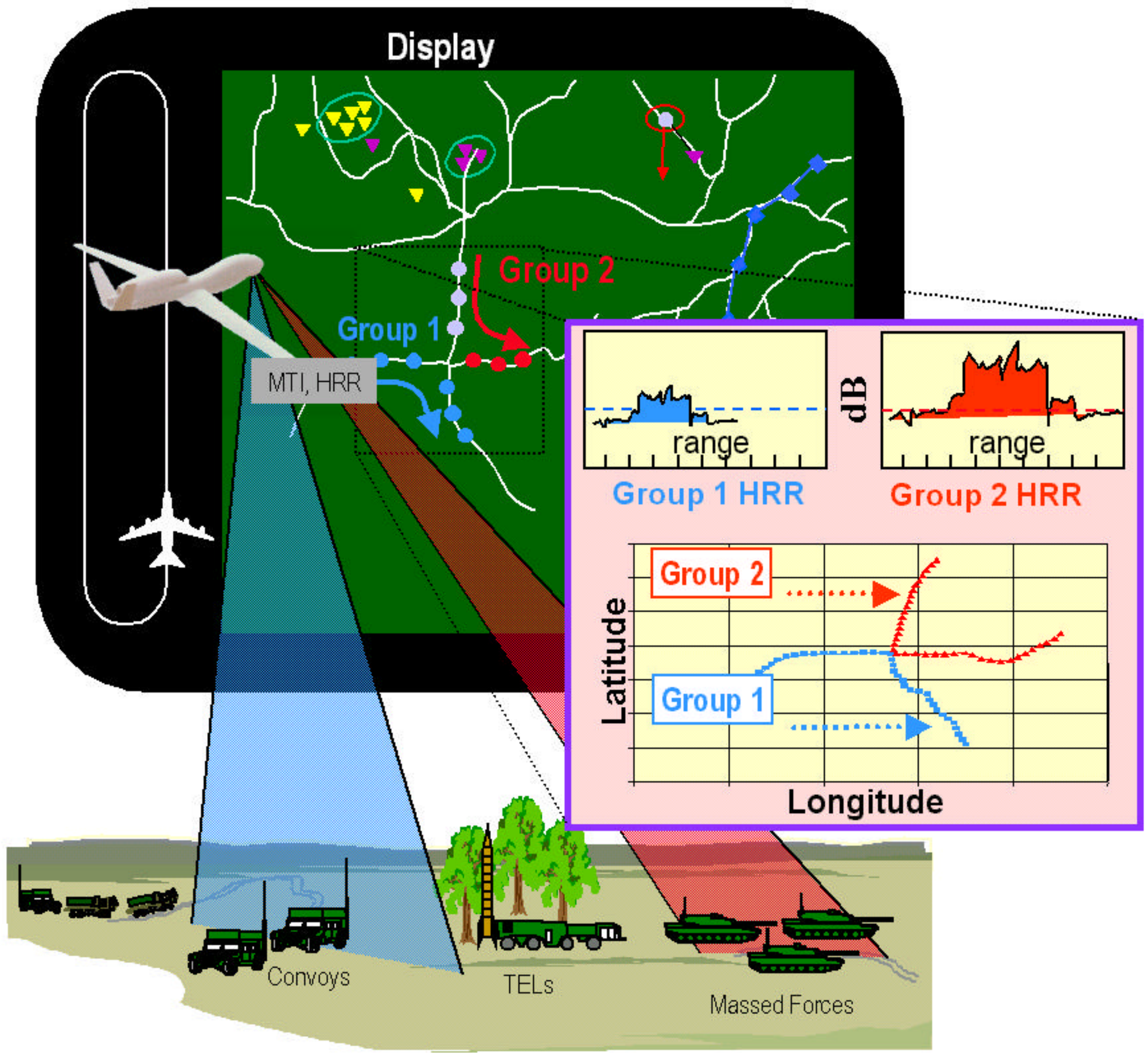
Analysis Goals

- Are there exploitable features?
- How persistent or stable are they?
- How well do they separate target tracks?
- Some general observations

Value of Moving Target Features for Track Maintenance



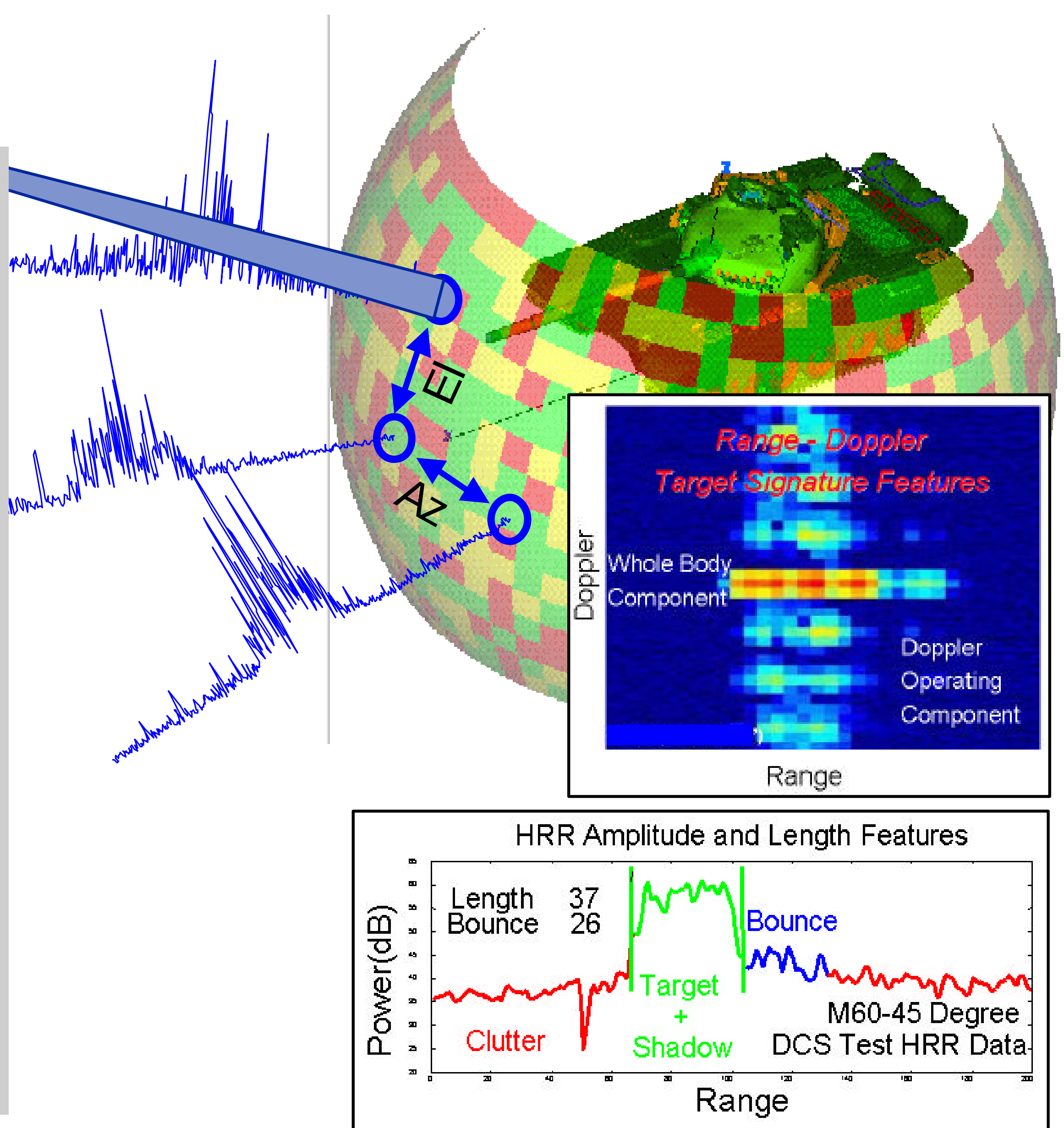
Feature Aided Tracking Concept



- Complex scenarios making tracking a difficult challenge
- Features are meant to aid the tracker's ability to maintain track
- Electrical length features
- Profile features
- Range-Doppler features

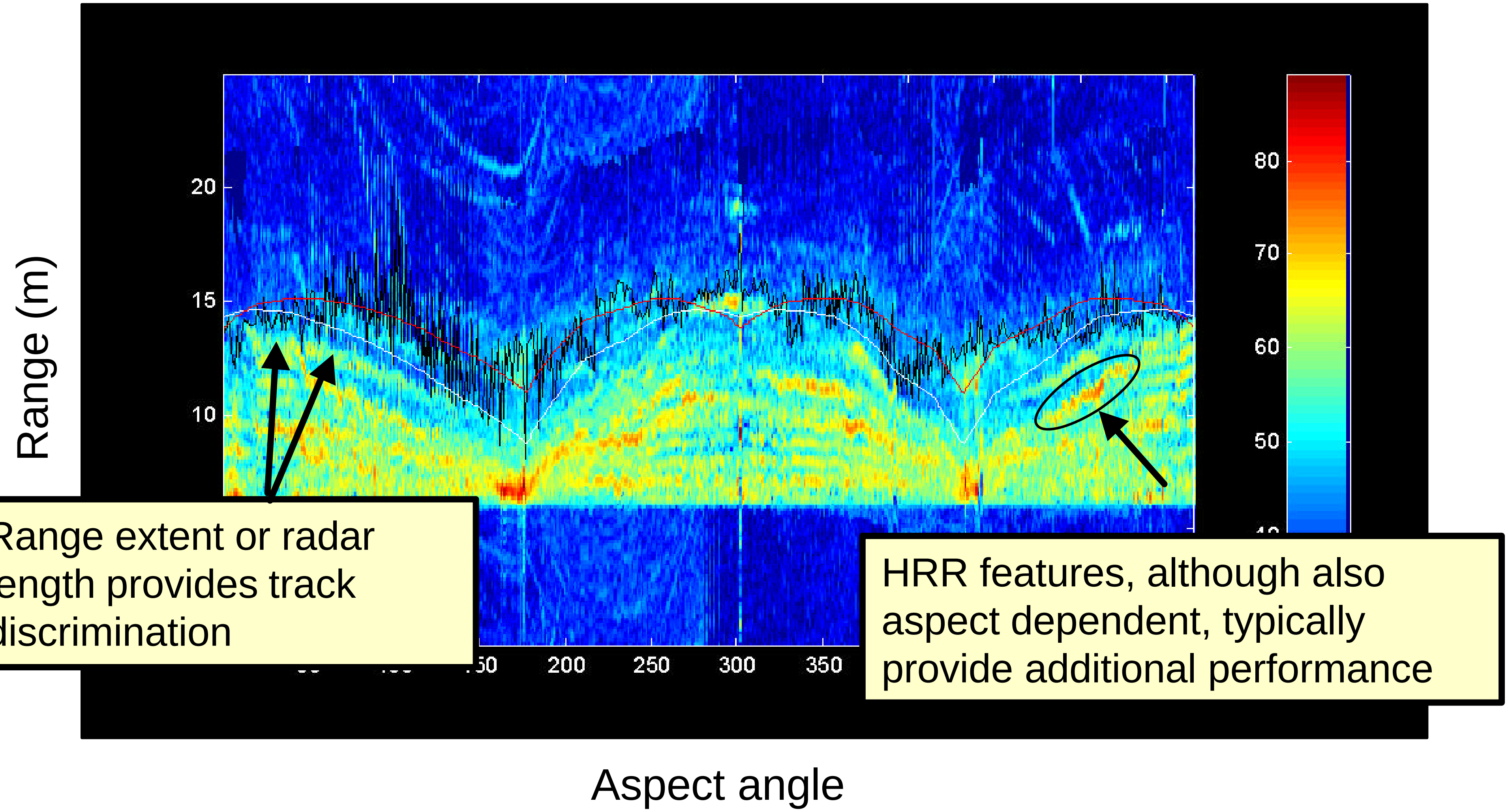
“HRR 101” For Tracking

- Imagine the target information as individual HRR “echoes”
- They return thru tiny windows centered around the target
- Target’s “<u>structural behavior</u>” is “encoded” as scatterer features.
- Superimposed during “transmission” is the vehicle’s “<u>kinematic behavior</u>” features.
- Resulting structural and kinematic behavior “decoded” or extracted as electrical length, HRR profile, or range doppler

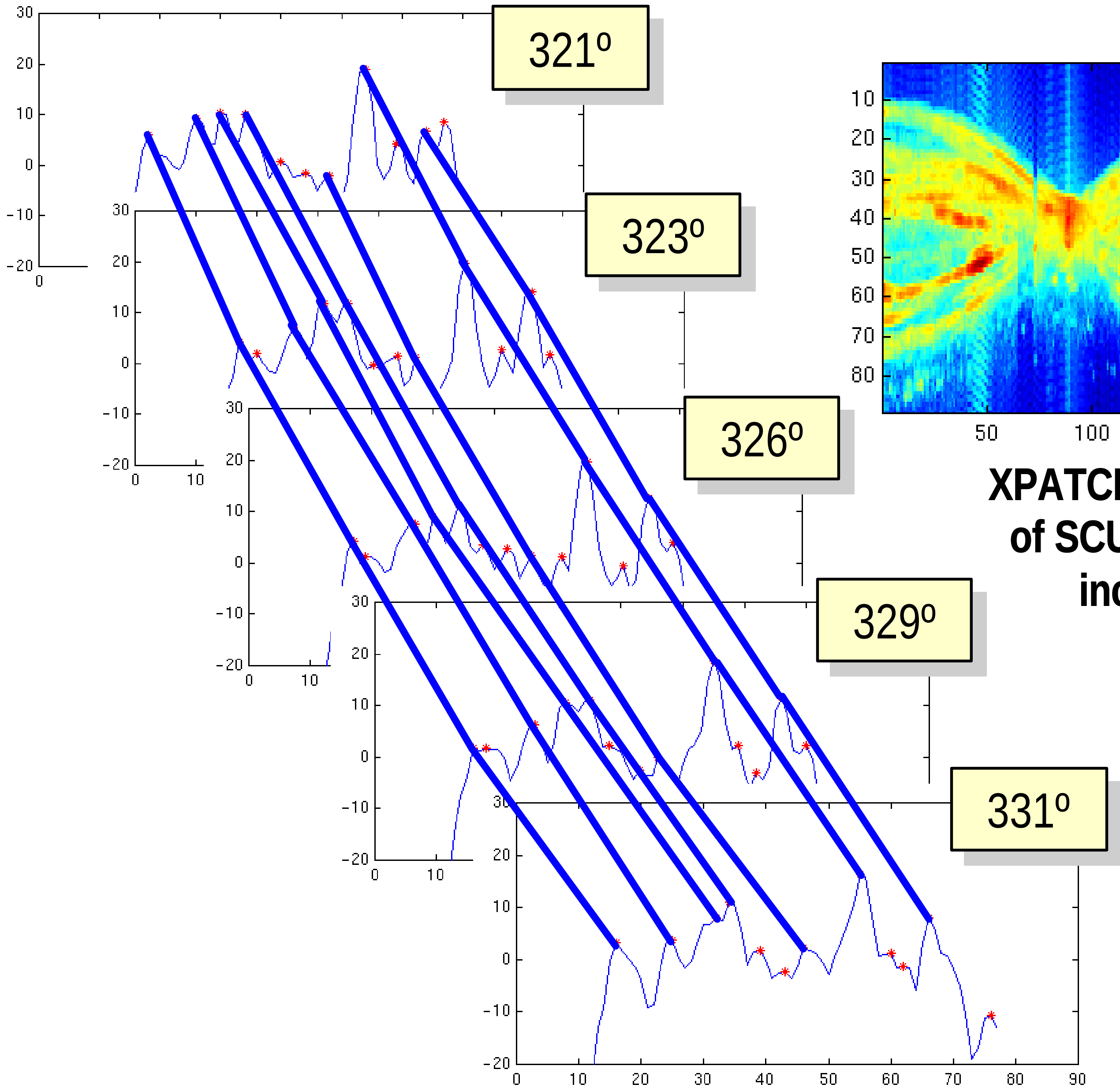


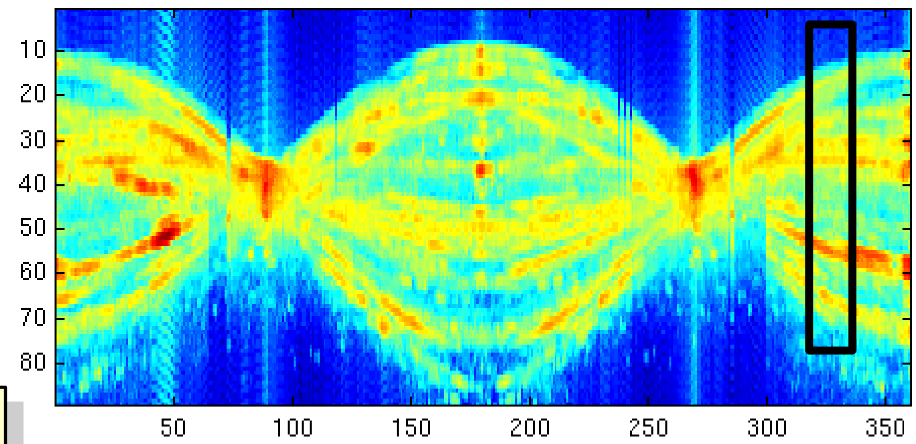
Feature Stability

HRR profile amplitude of M813 versus range and aspect angle (DCS collection)



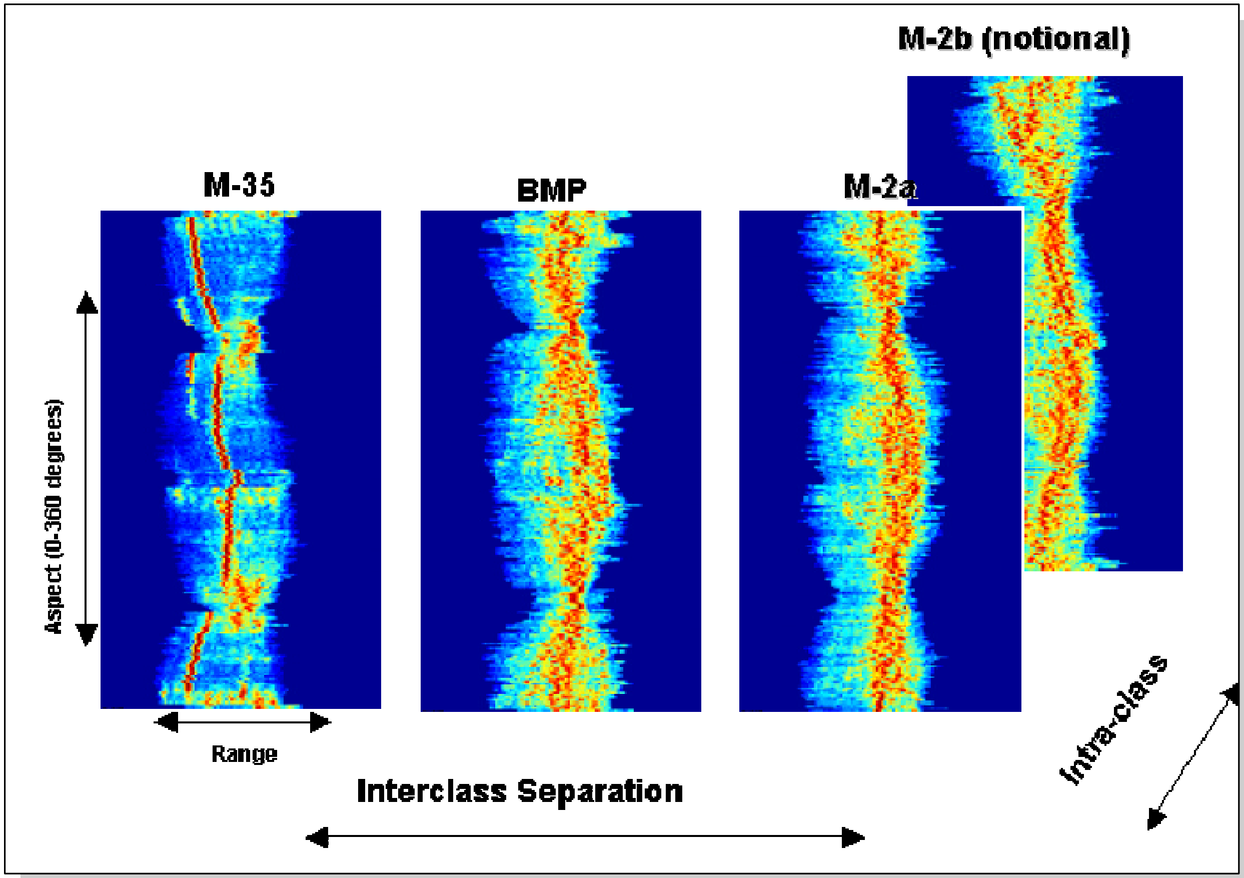
Persistent HRR Peaks





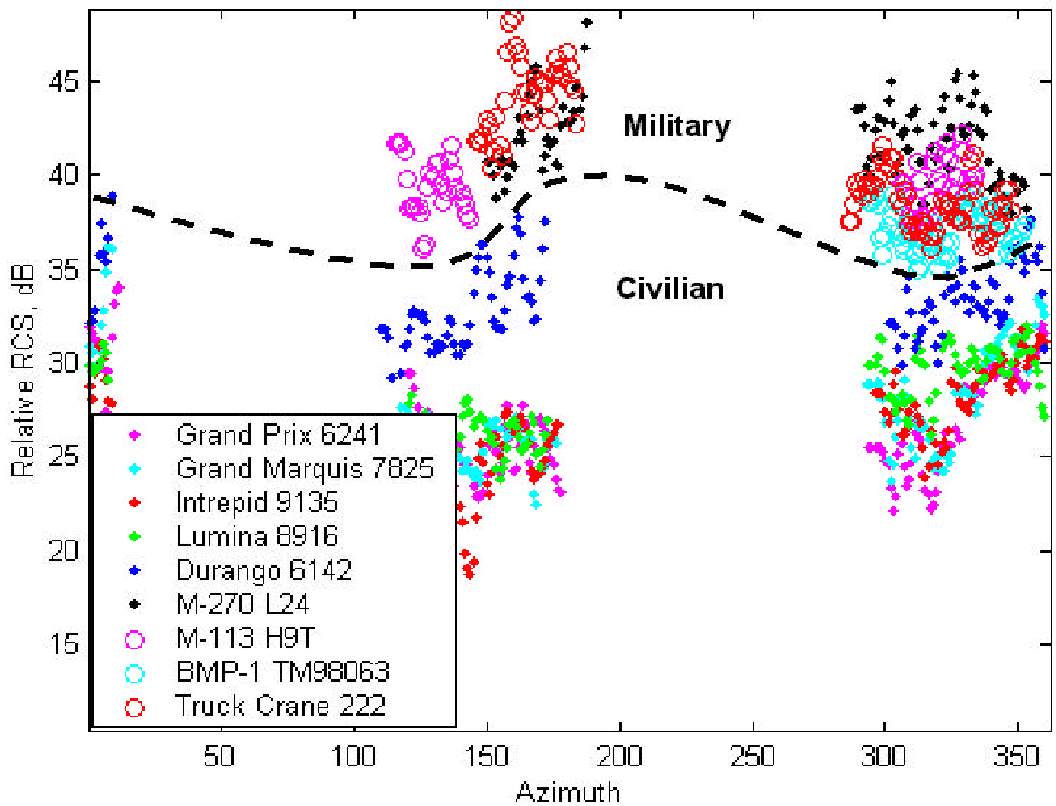
XPATCH-generated HRR profiles of SCUD TEL (1-degree aspect increments, 15-degree depression)

Feature Separability



- <u>Electrical Length</u>: Targets with different radar lengths can be tracked using length features (M-35 and BMP)
- <u>Profile</u>: Targets of similar length may be tracked using shape features (BMP - M2a)
- <u>Range-Doppler</u>: Targets of similar shape may be tracked using doppler or special fingerprinting features (M-2a and M2b)

Military vs Civilian Features

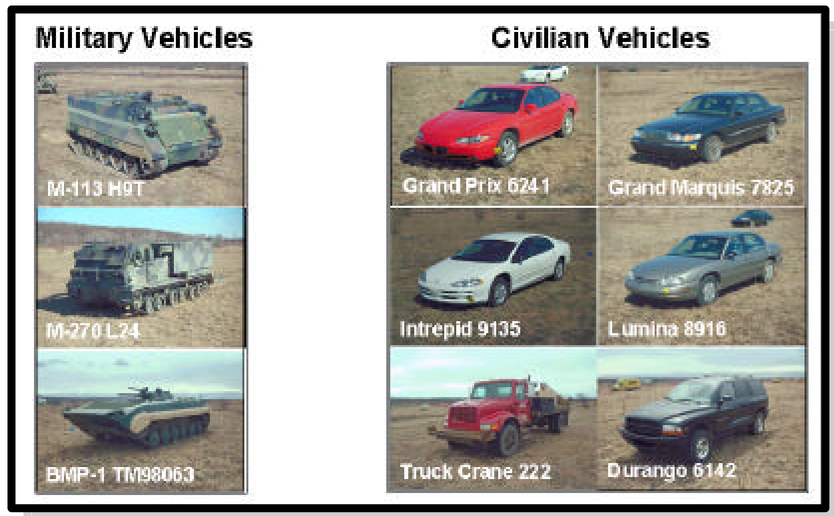


Military

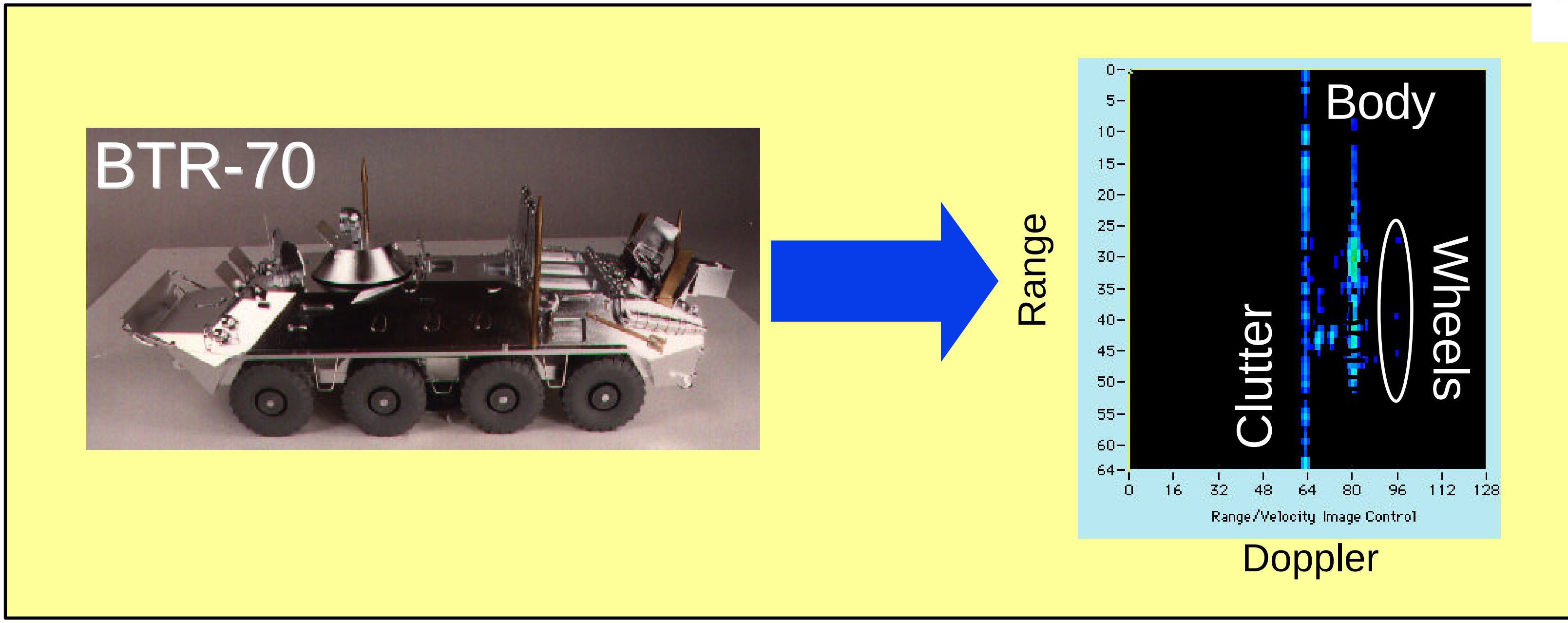
- Complex return due to richer scatterer geometry and fabrication materials used (steel, reactive armor).

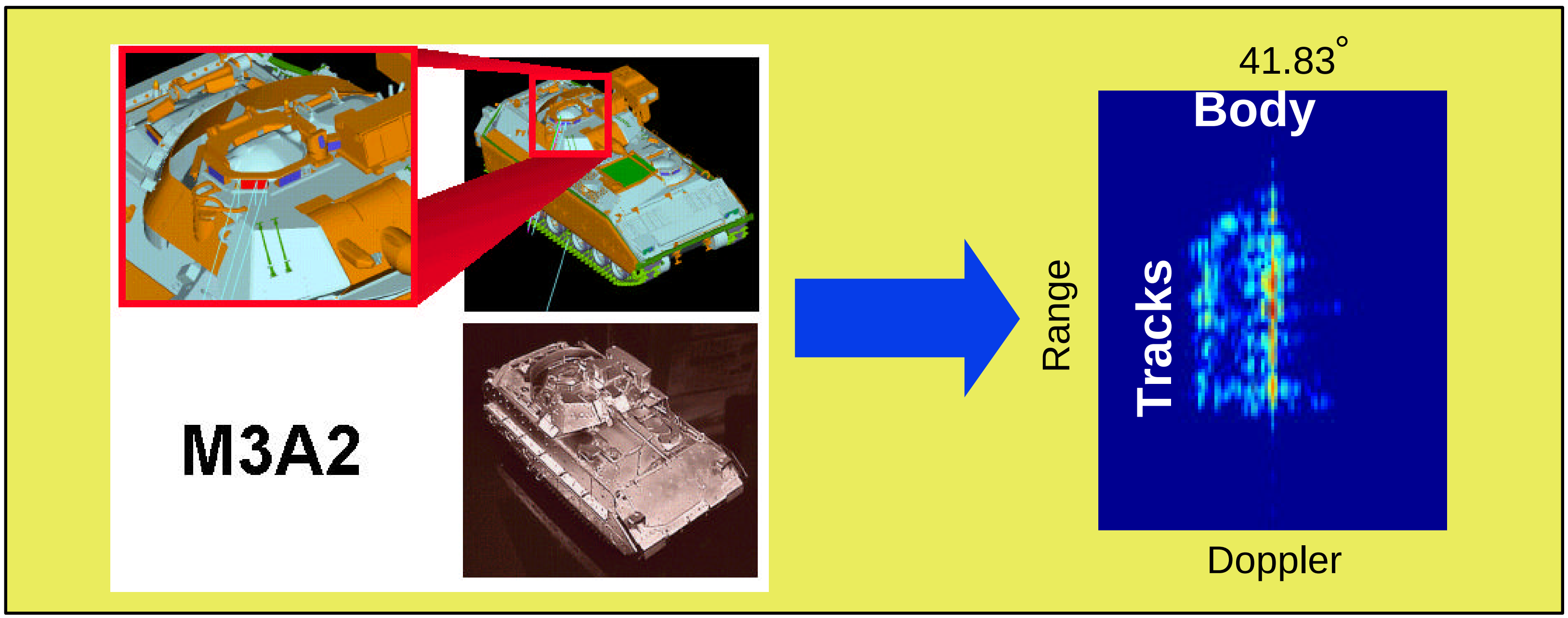
Civilian

- Simpler return (by ~10dB) due to smooth aerodynamic contours and fabrication materials used (fiberglass).



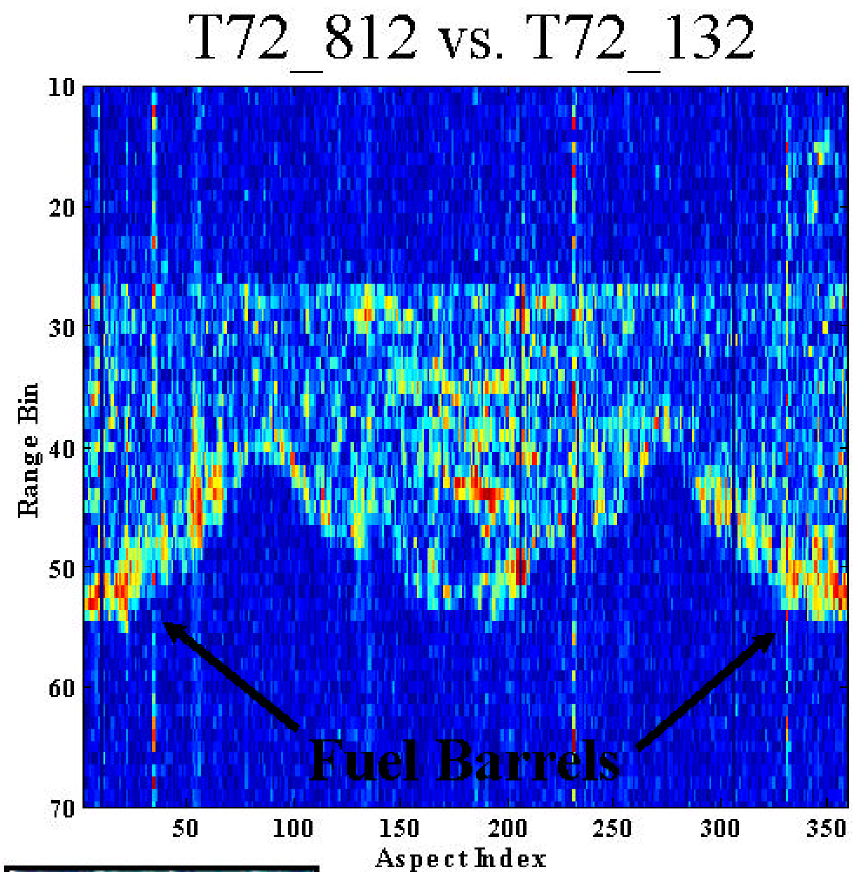
Doppler Features to Aid Tracking

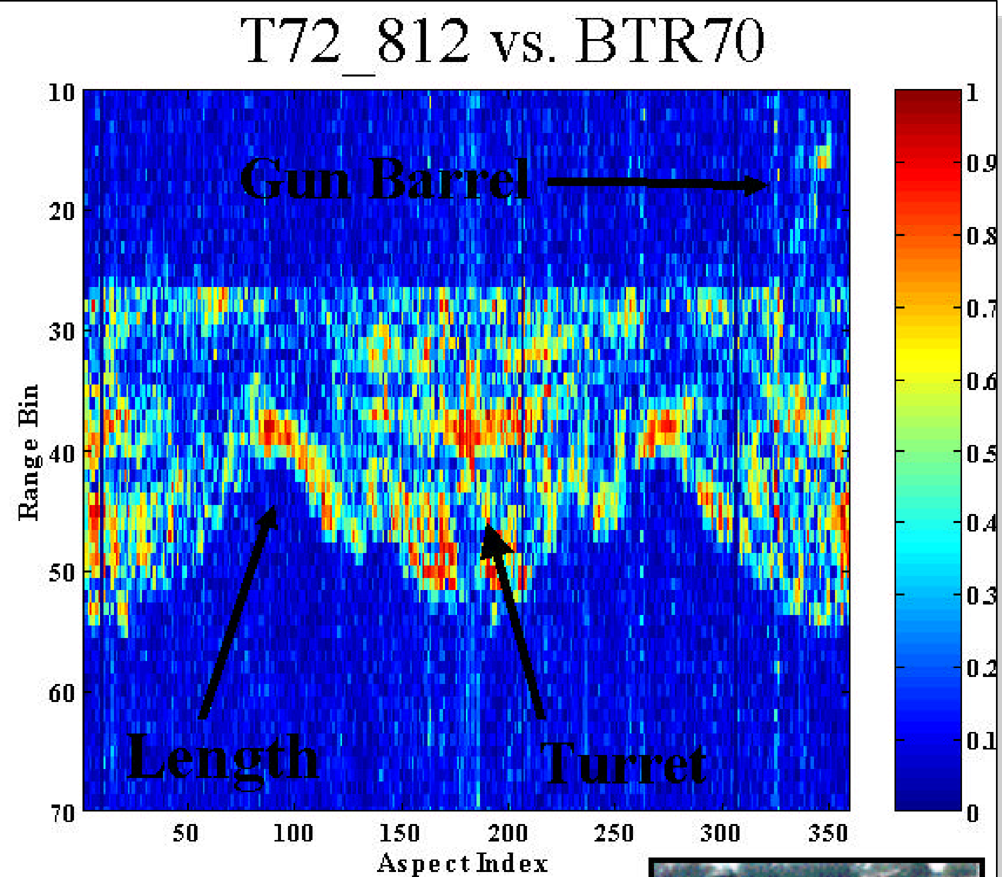




Delta Analysis of Features

Average Delta Plots vs Range and Aspect





T72

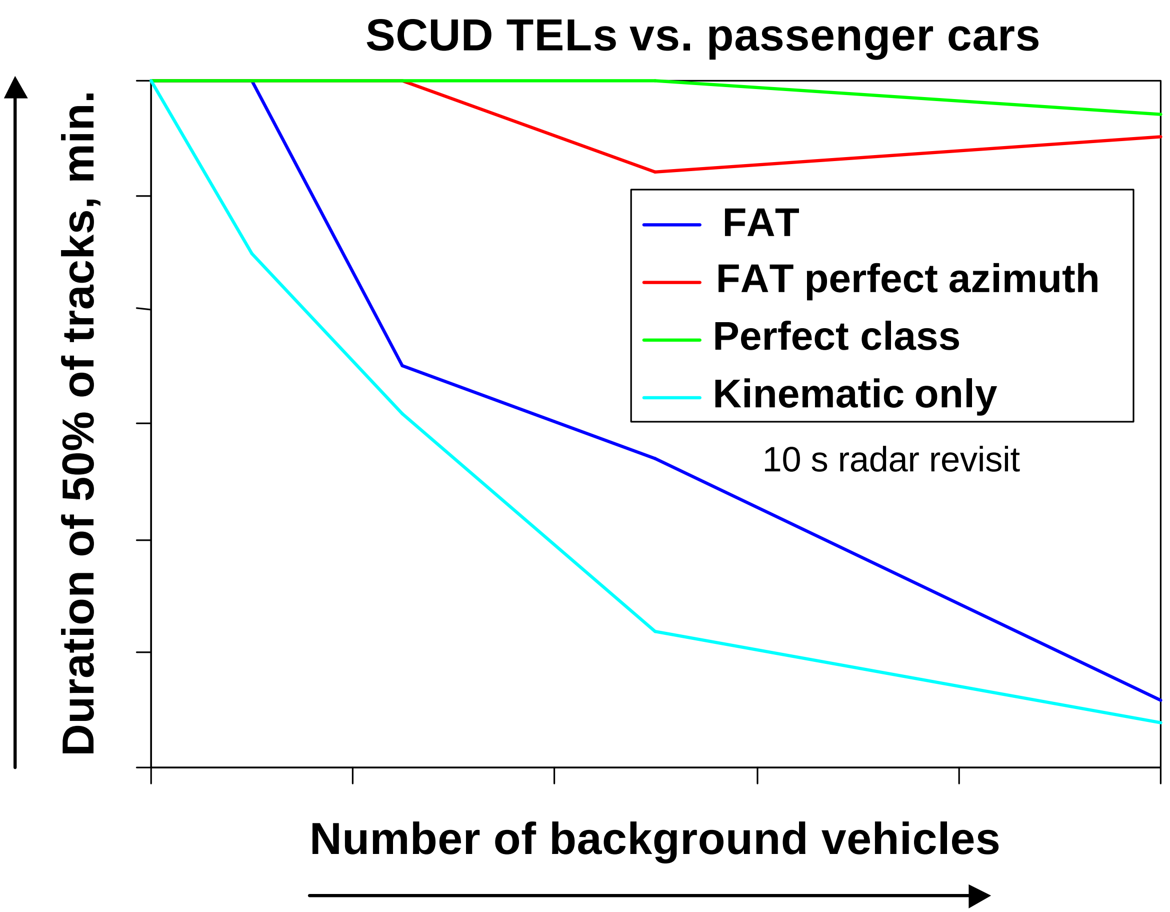
For Normalized Profiles…

Leading Edge is Stable, but not Separable.

Trailing Edge is not Stable, but is Separable.

BTR70

A Tracking Experiment



- Kinematic Only: baseline
- FAT: use radar length as feature. Assume moderate aspect accuracy. Noticeable improvement over kinematic only.
- FAT perfect azimuth: illustrates the important contribution of tracker accuracy.
- Perfect class: illustrates an upper bound of track ID maintenance performance as goal of improved features.

Some Concluding Observations

- Investigated 3 basic features: electrical length, HRR amplitude (peaks and valleys), and complex Range Doppler.
  - Radar length differs from physical length and depends on angles and vehicle type. Length offers track discrimination when targets are significantly different.
  - HRR amplitudes looks to offer noticeable improvement over length and particularly promising for “Military vs Civilian” tracks. Performance is radar, collection geometry, & tgt dependent.
  - Range-Doppler feature for improved track ID maintenance subject to continuing research but looks promising at this stage particularly for Wheel vs Tread track ID.
- Maximum benefit realized with good azimuth knowledge
- Moving target features capture the structural and kinematic behavior of moving targets and thus expected to substantially improve ability to maintain track ID for extended durations in complex scenarios.

AMSTE II
Bidders Briefing

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Special Projects Office

AMSTE II Description

Stephen Welby, DARPA

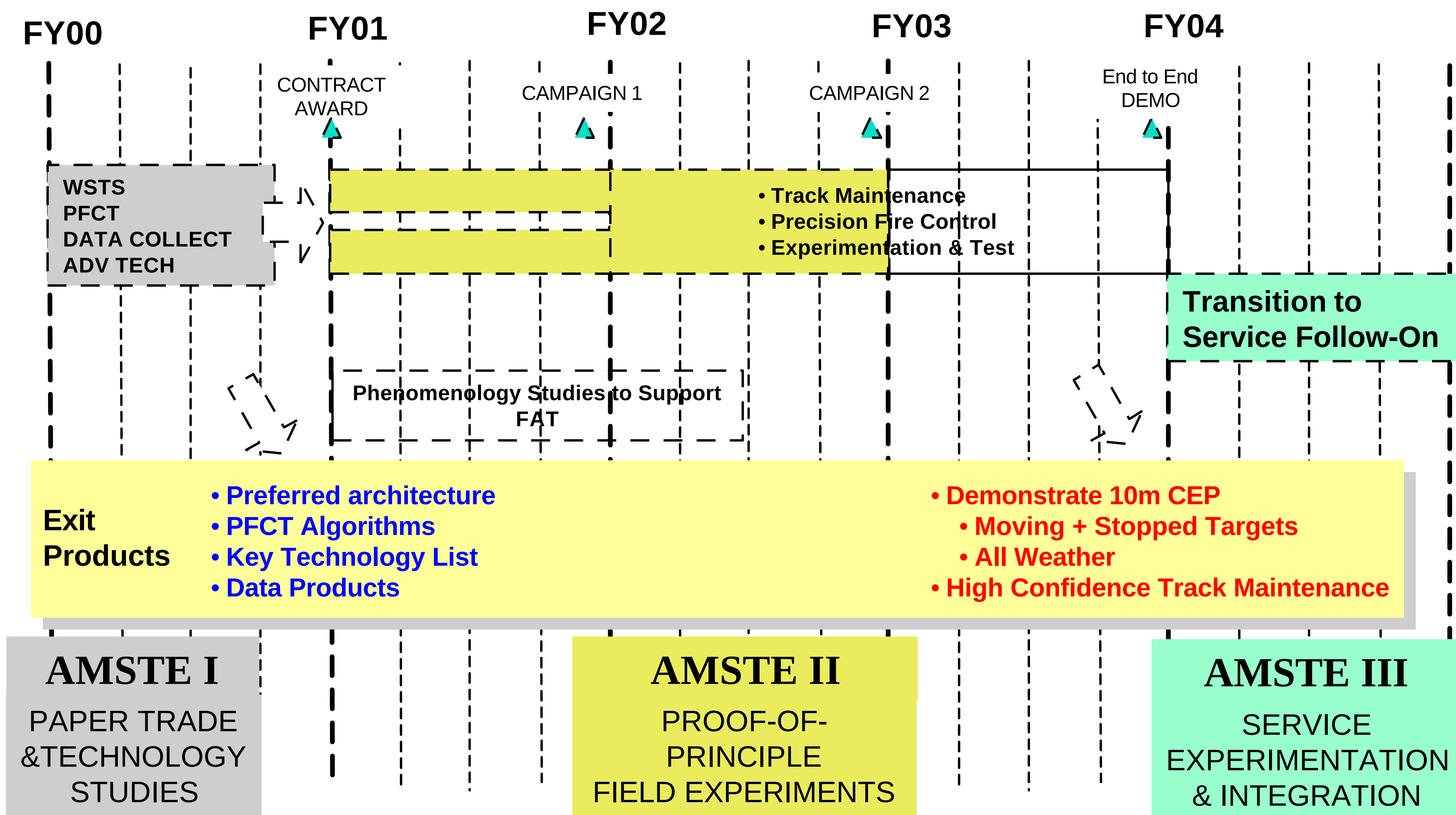
AMSTE Status and Plan

Special Projects Office

- DARPA/SPO is completing initial studies and experimental efforts to better understand the problem
  - Weapon System Trade Studies (WSTS)
  - Precision Fire Control Tracking (PFCT) Studies
  - Field data collection activities
- AMSTE Phase II will:
  - Integrate weapon system capability for near term demo of the AMSTE concept
  - Address key technical challenges and design trades
  - Design, build, and demonstrate an AMSTE experimentation system capable of real time operation

AMSTE Program
Schedule and Milestones

Special Projects Office



Outline

- Objective of this PRDA (AMSTE II)
- Programmatic Approach
- AMSTE II Activities
- Roles and Responsibilities
- Description of Experimental Campaigns
- Contract Technical Products Expected

Objective of this PRDA (AMSTE II)

Special Projects Office

- The purpose of AMSTE II is to
  - Develop and integrate an experimental system
  - Develop the required technology
  - Conduct AMSTE Proof of Principle Experiments

Scope of AMSTE II

- AMSTE function begins when a target with ID is designated to the system
- AMSTE function ends with weapon delivery (BDA is not included)

Programmatic Approach

- Series of yearly experiments posing increasingly difficult technical challenges
  - Each set of experiments structured to explore and evaluate system technologies that have been developed

- Progression of Emphasis

FY01: Fire-Control/Accuracy

FY02: + Track Maintenance/Association

FY03: + Battle Management/C3

AMSTE II is about demonstrating a capability, not delivering a box

Programmatic Approach (Cont)

Special Projects Office

- Government not dictating configuration or components of experimental systems
  - Offeror determines functional allocation among system elements
  - Offeror selects platforms, sensors, comms, and weapons
- Experimental system need not mimic any particular operational configuration
  - Technical relevance should be maintained
- Timeframe for sensor and system technologies is 2007
  - Testbed or prototype systems used in experimentation should be expected to be in later development stage by 2007

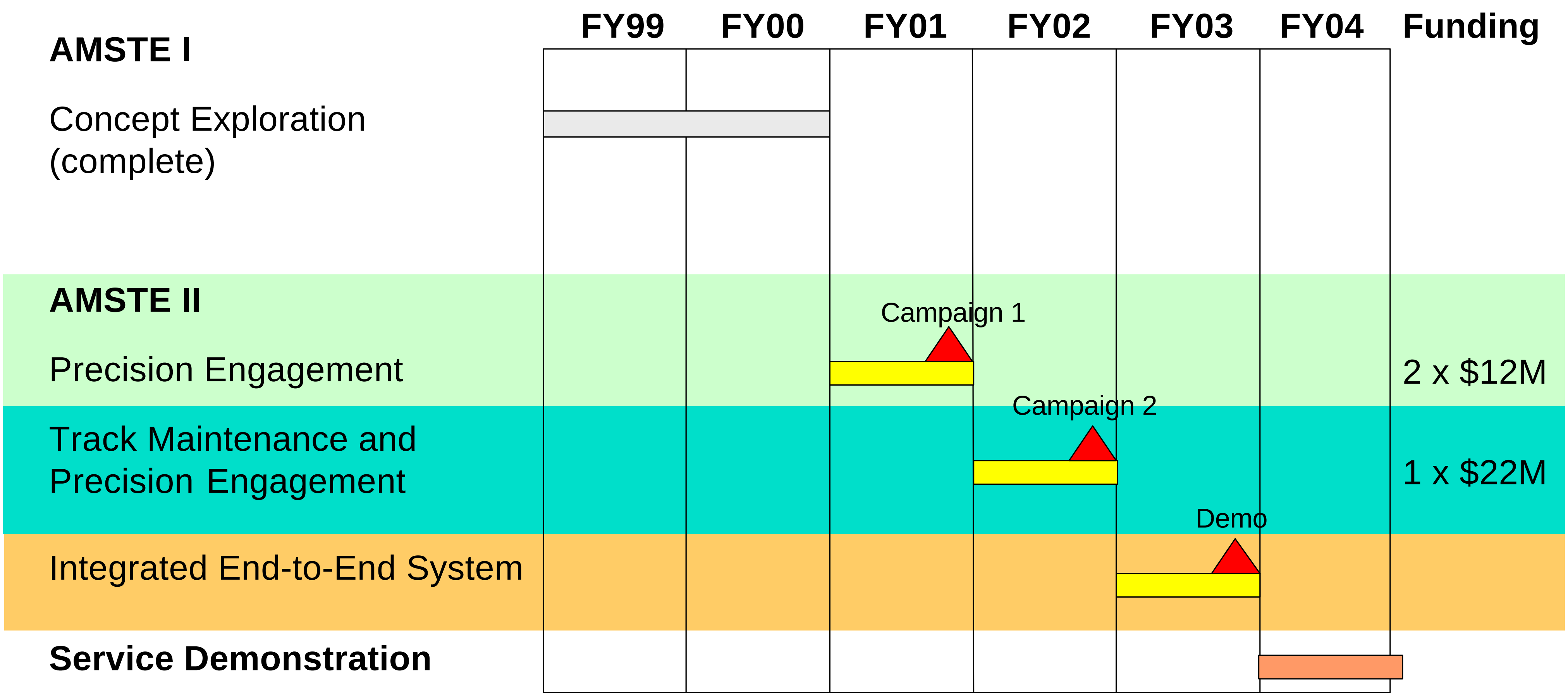
Innovative approaches are encouraged

Programmatic Approach (Cont)

Special Projects Office

- Overlapping analysis, development, integration, and experimentation cycles
- Yearly opportunities to show progress and experiment with potential solutions
  - Experimental objectives expanded in phase with experimental system capability

AMSTE Schedule



- **Should be described and costed in your proposal**
- **Should be described with ROM cost in this proposal**
- **Out year effort not part of this PRDA**

Program Objectives by Year

- FY 01 - Precision Engagement Experimentation
  - Integrate the experimental system
  - Conduct weapon delivery proof of feasibility and related experiments
  - Develop critical technologies required for the later phases
- FY 02 - Track Maintenance and Precision Engagement Experimentation
  - Integrate new capabilities into the experimental system
  - Demonstrate high-confidence target ID maintenance
  - Demonstrate precision engagement in complicated target motion scenarios
  - Prepare for FY03 demonstrations
    - Develop critical technologies
    - Define experimental system and experiment(s)
- FY 03 - Integrated End-to-End Demonstration
  - Program capstone demonstrations
  - Participate in service exercise

- **Should be described and costed in your proposal**
- **Should be described with ROM cost in this proposal**
- **Should be described, but not costed in this proposal**

AMSTE II Activities

- AMSTE II program requires extensive work and expertise in four areas:
  - Technology Development
  - Experimental System Integration
  - Experiment Planning
  - Experimentation and Demonstration
- Proposal and SOW should address these areas

Technology Development

- Advance the state-of-the-art in key technologies
  - Focus on items needed to successfully complete experiments
  - Specific technologies dependent upon contractors approach
- Experiment scenarios intended to specify increasing performance goals
  - Yearly experiments require yearly advances in technology
  - May require multiple approaches to mitigate risk
  - Data from early experiments should support continued technology development

Technology development must be proactive to support future experiments

Experimental System Integration

Special Projects Office

- Establish experimental system requirements
  - Flow requirements down from system level to sub-system and component levels
  - Establish and implement Interface Control Documents
- Acquire, develop, and/or modify hardware and software
- Incorporate technology developments into experimental system
- Establish and execute plan for component and subsystem testing
  - Qualification and characterization testing
  - Risk reduction activities
- Integrate the system and perform initial testing

Experiment Planning

Special Projects Office

- Refine experiment descriptions
  - Develop scenarios and conditions that fully test system performance envelope critical issues
  - Experiments should extend beyond the system performance envelope
- Model system behavior and predict system performance
- Develop test plans as members of Test Working Group
- Conduct an Experiment Design Review
- Obtain approvals and authorizations necessary for field experimentation

Experimentation and Demonstration

Special Projects Office

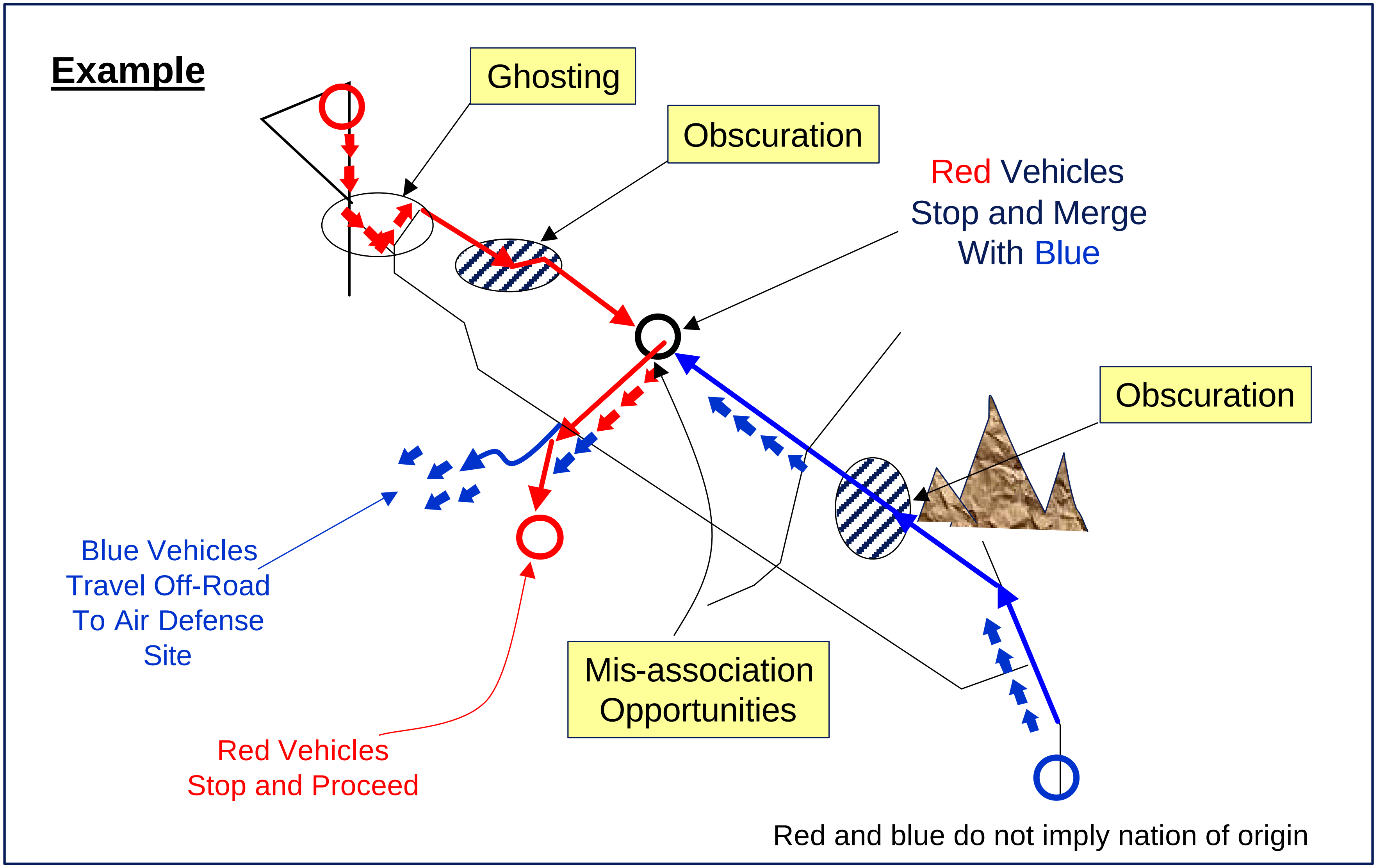
- Deploy and operate experimental system per test plan
- Orchestrate test assets and coordinate test team
- Exercise AMSTE II system
  - Explore system behavior (Experimentation)
  - Show system capability (Demonstration)
  - Collect data for development of further system capabilities
- Data Analysis
  - Evaluate measures of performance and system operation
  - Validate performance predictions (simulations, error budgets)
  - Document achievements and shortcomings

Roles and Responsibilities

Special Projects Office

- Contractor is responsible for all aspects of the experimental system, including:
  - Platforms, sensors, communications equipment, weapons/ordnance, data links, ground equipment, test, etc.
  - Software (e.g., sensor, network, tracking, weapons/ordnance, resource management)
  - Analysis, prediction, and validation of system performance
  - Design and conduct of experiments
  - Participation in Test Working Group
  - Operation and maintenance of the system
  - Analysis of test data
- Government will:
  - Review and approve test plans
  - Serve as chair of Test Working Group
  - Perform liaison with the test range(s)
  - Provide range services, targets, and target ground truth data
    - For purposes of proposal assume Nellis

Experimental Campaigns



Description of Experimental Campaigns

Special Projects Office

- Experiment descriptions that follow are intended to help define the capability desired in the experimental system at a point in time
  - Not meant to be exhaustive or exclusive
- Ranges of parameters are illustrative
  - May not apply directly to the offeror's experimental system
  - Intended to convey the complexity and challenge of the experiment
- Experiment plans will be developed during the course of the contract

Outline of Field Experiments

Special Projects Office

- Campaign 1: Precision Engagement (PE) (FY01)
  - Experiment 1A: Weapon Delivery Demo*
  - Experiment 1B: End-game Tracking
- Campaign 2: Integrated Track Maintenance (TM) and Precision Engagement (FY02)
  - Experiment 2A: Track Association
  - Experiment 2B: Move-Stop-Move Algorithms*
  - Experiment 2C: Complex Motion and Target Density
- Campaign 3: Integrated End-to-End System (FY03)
  - Experiment 3A: Evaluation of System Integration*
  - Experiment 3B: Participation in Unscripted Exercise

* Live weapon delivery expected

A "live weapon delivery" may use an inert weapon

Progression of Experimental Challenges

Challenge Conditions	Campaign 1	Campaign 2	Campaign 3
Accuracy:	10 m CEP →		
Target Behavior	Benign	Evasive	Unscripted
Terrain Type	Flat	Hilly	Hilly
Track Maintenance:	1 - 5 min	20 min	As Required
# of Vehicles	Few	Many	Many
Complexity	Ghosting	Not Separable with Kinematics	Unscripted
Automation:	PE	TM to PE	End to End

Campaign 1: Precision Engagement

Special Projects Office

	Campaign 1		Campaign 2			Campaign 3	
	Exp 1A	**Exp 1B**	**Exp 2A**	**Exp 2B**	**Exp 2C**	**Exp 3A**	**Exp 3B**
	Wpn Del Demo*	End Game Tracking	Track Association	Move-Stop-Move	Complex Motion	System Integration	Service Exercise
Target Behavior							
Maneuver	0.1 g	0.3 g	0.3 g	0.3 g	0.5 g	varied	varied
Speed	30 mph	30 mph	15 to 30 mph	10 to 30 mph	5 to 50 mph	5 to 50 mph	5 to 50 mph
Speed Variation	Mild	Moderate	Moderate	Moderate	Rapid	Moderate	Rapid
On/Off Road	Off	Off	Off	Off	On/Off/On	On/Off/On	On/Off/On
Stopping	No	No	No	Yes	Yes	Yes	Yes
Terrain	Flat	Flat	Flat	Flat	Hilly	Hilly	Hilly
Scenario Complexity							
Track Maint Duration	1 min	5 min	20 min	20 min	20 min	20 min	20 min
Total # Vehicles	1	6	6	6	30	30	100
Mis-assoc opportunities	n/a	Ghosting	0.3/min/tgt	0.3/min/tgt	1.0/min/tgt	1.0/min/tgt	1.0/min/tgt
# Targets in Track	1	1	6	6	6	12	12
Obscuration	None	None	None	None	Occasional	Occasional	Occasional
Nomination/Handover	Scripted	Scripted	Scripted	Scripted	Scripted	Unscripted	Unscripted

Potential Technology Solutions:

- Accurate multi-laterated GMTI
- Netted sensors and weapons
  - Gridlocking/georegistration, low latency comms, weapon guidance, weapon data link and IFTUs, multi-vehicle tracking

Campaign 2: Track Maintenance and Precision Engagement

	Campaign 1		Campaign 2			Campaign 3	
	Exp 1A	**Exp 1B**	**Exp 2A**	**Exp 2B**	**Exp 2C**	**Exp 3A**	**Exp 3B**
	Wpn Del Demo	End Game Tracking	Track Association	Move-Stop-Move*	Complex Motion	System Integration	Service Exercise
Target Behavior							
Maneuver	0.1 g	0.3 g	0.3 g	0.3 g	0.5 g	varied	varied
Speed	30 mph	30 mph	15 to 30 mph	10 to 30 mph	5 to 50 mph	5 to 50 mph	5 to 50 mph
Speed Variation	Mild	Moderate	Moderate	Moderate	Rapid	Moderate	Rapid
On/Off Road	Off	Off	Off	Off	On/Off/On	On/Off/On	On/Off/On
Stopping	No	No	No	Yes	Yes	Yes	Yes
Terrain	Flat	Flat	Flat	Flat	Hilly	Hilly	Hilly
Scenario Complexity							
Track Maint Duration	1 min	5 min	20 min	20 min	20 min	20 min	20 min
Total # Vehicles	1	6	6	6	30	30	100
Mis-assoc opportunities	n/a	Ghosting	0.3/min/tgt	0.3/min/tgt	1.0/min/tgt	1.0/min/tgt	1.0/min/tgt
# Targets in Track	1	1	6	6	6	12	12
Obscuration	None	None	None	None	Occasional	Occasional	Occasional
Nomination/Handover	Scripted	Scripted	Scripted	Scripted	Scripted	Unscripted	Unscripted

Potential Technology Solutions:

- Advanced tracking algorithms
  - Cooperative tracking, move-stop-move algorithms, feature aided tracking
- Mode control algorithms

Campaign 3: Systems Integration and BM/C3

Special Projects Office

	Campaign 1		Campaign 2			Campaign 3	
	Exp 1A	**Exp 1B**	**Exp 2A**	**Exp 2B**	**Exp 2C**	**Exp 3A**	**Exp 3B**
	Wpn Del Demo	End Game Tracking	Track Association	Move-Stop-Move	Complex Motion	System Integration*	Service Exercise
Target Behavior							
Maneuver	0.1 g	0.3 g	0.3 g	0.3 g	0.5 g	varied	varied
Speed	30 mph	30 mph	15 to 30 mph	10 to 30 mph	5 to 50 mph	5 to 50 mph	5 to 50 mph
Speed Variation	Mild	Moderate	Moderate	Moderate	Rapid	Moderate	Rapid
On/Off Road	Off	Off	Off	Off	On/Off/On	On/Off/On	On/Off/On
Stopping	No	No	No	Yes	Yes	Yes	Yes
Terrain	Flat	Flat	Flat	Flat	Hilly	Hilly	Hilly
Scenario Complexity							
Track Maint Duration	1 min	5 min	20 min	20 min	20 min	20 min	20 min
Total # Vehicles	1	6	6	6	30	30	100
Mis-assoc opportunities	n/a	Ghosting	0.3/min/tgt	0.3/min/tgt	1.0/min/tgt	1.0/min/tgt	1.0/min/tgt
# Targets in Track	1	1	6	6	6	12	12
Obscuration	None	None	None	None	Occasional	Occasional	Occasional
Nomination/Handover	Scripted	Scripted	Scripted	Scripted	Scripted	Unscripted	Unscripted

Potential Technology Solutions:

Improved connectivity
Kill chain automation
Engagement planning
Platform, comms, and sensor resource management

Experiment Conditions

Special Projects Office

	Campaign 1		Campaign 2			Campaign 3	
	Exp 1A Wpn Del Demo	**Exp 1B** End Game Tracking	**Exp 2A** Track Association	**Exp 2B** Move-Stop-Move	**Exp 2C** Complex Motion	**Exp 3A** System Integration	**Exp 3B** Service Exercise
Target Behavior							
Maneuver	0.1 g	0.3 g	0.3 g	0.3 g	0.5 g	varied	varied
Speed	30 mph	30 mph	15 to 30 mph	10 to 30 mph	5 to 50 mph	5 to 50 mph	5 to 50 mph
Speed Variation	Mild	Moderate	Moderate	Moderate	Rapid	Moderate	Rapid
On/Off Road	Off	Off	Off	Off	On/Off/On	On/Off/On	On/Off/On
Stopping	No	No	No	Yes	Yes	Yes	Yes
Terrain	Flat	Flat	Flat	Flat	Hilly	Hilly	Hilly
Scenario Complexity							
Track Maint Duration	1 min	5 min	20 min	20 min	20 min	20 min	20 min
Total # Vehicles	1	6	6	6	30	30	100
Mis-assoc opportunities	n/a	Ghosting	0.3/min/tgt	0.3/min/tgt	1.0/min/tgt	1.0/min/tgt	1.0/min/tgt
# Targets in Track	1	1	6	6	6	12	12
Obscuration	None	None	None	None	Occasional	Occasional	Occasional

Numerical Goals:

10 meter accuracy (CEP) for weapon delivery without a seeker
3 meter accuracy (CEP) for weapon delivery with a seeker
20 minute high-confidence track maintenance

Experiment Conditions

Special Projects Office

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Stopping	No	No	No	Yes	Yes	Yes	Yes
Terrain							
Scenario Complexity							
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Total # Vehicles							
Mis-assoc opportunities	n/a	Ghosting	0.3/min/tgt	0.3/min/tgt	1.0/min/tgt	1.0/min/tgt	1.0/min/tgt
# Targets in Track							
Obscuration							

Benign — Evasive — Unscripted

Steady, even motion — Erratic, unpredictable

Constant — Start-stop, varied duration & speed

Single — Few — Many

Short (minute) — Long (several tens of minutes)

Numerical Goals:

10 meter accuracy (CEP) for weapon delivery without a seeker
3 meter accuracy (CEP) for weapon delivery with a seeker
20 minute high-confidence track maintenance

Definition of Experiment Terms for Target Behavior

- Maneuver
  - Lateral acceleration of target, used to define how sharp a turn is being executed. The time duration is 1 - 15 seconds.
- Speed
  - Average speed of the vehicle when moving.
- Speed Variations
  - Fluctuation in speed due to driver inattention (mild), terrain conditions (moderate), or deliberate action (rapid).
- On/Off Road
  - Used to describe the vehicle's likely behavior (both short term and long term) and the availability of a road database. On/Off/On implies possible transitions.
- Stopping
  - Defines whether the experiment script will call for a target vehicle to stop between nomination and (actual or implied) weapon impact
- Terrain
  - Intended to test the robustness of the use of terrain elevation databases

Definition of Experiment Terms for Scenario Complexity

- Track Maintenance Duration
  - The amount of time after nomination that the system is expected to provide high-confidence target tracking
- Total # Vehicles
  - The number of vehicles within the area of interest, including potential targets and background vehicles. The size and shape of "area of interest" is dependent on the system's intended operation and may extend over multiple radar beam footprints
- Mis-association Opportunities
  - Intended to indicate effective traffic density. The number given is the average rate (opportunities per minute per target vehicle) that kinematically-unresolvable confuser returns compete with the true target return. In the PE experiments, the emphasis is on ghosting, which is associated with closely spaced vehicles during end-game.
- # Targets in Track
  - The number of nominations active (in TM or PE) simultaneously, located within a single area of interest
- Obscuration
  - Shadowing of the target from one or more sensors. Experiments will be designed to induce outages from 1-30 seconds.

Definition of Experiment Terms for Nomination/Handover

- Nomination/Handover
  - The intent is to test the automation of the kill chain. In the unscripted case, the system should accept a nomination and prosecute the target through precision engagement with reasonable operator workload. In cases where this function is scripted, some or all of the mode transitions may be manually initiated.

Definition of Experiment MOEs

- Engagement of Moving Surface Targets
- Precision Operation
- All-Weather Operation
- Availability
- Survivability
- Operational Suitability

MOE Definitions

- Engagement of Moving Surface Targets
  - The ability to detect, track, and engage surface targets displaying intermittent or continuous motion
- Precision Operation
  - Having timely and accurate target state data delivered to and in reference frame useable by all system elements

MOE Definitions (cont.)

Special Projects Office

- All-Weather Operation
  - Ability to employ the system in adverse weather and visibility conditions in which it is likely to be needed
  - Applies to all elements of the system including sensors and sensor platforms, communications, weapons and weapon platforms
- Availability
  - Range of military situations over which the system provides meaningful utility

    A system with good availability in this sense will work with a wide variety of geographic conditions, target sets, rules-of-engagement, and force structure.
  - Continuity of system performance in a given military setting

    A system with good availability in this sense provides consistent and predictable performance across the battlefield and over time against a wide variety of terrain and background (traffic) conditions.

MOE Definitions (cont.)

Special Projects Office

- Survivability
  - Ability to employ the system in a wide variety of military situations with acceptable attrition rates of the system elements. Survivability may be enhanced either by increasing the safety of high-value assets, or by lowering the value of the assets that are at risk
- Operational Suitability
  - Effectiveness and ease of employment and use for operational forces. Required actions must represent a reasonable workload for operators and decision makers and be supported by adequate data

Technical Products Expected

Special Projects Office

- Documentation of systems analyses
  - System and hardware descriptions
  - Performance predictions and description of models and simulations
  - Requirements and design trades
- Semi-annual technical report
  - Technology development progress and findings
  - Test data analysis
- Interface Control Documents
- Test plans
- Test data

Delivery of Hardware and Software is not Desired

AMSTE II Summary

Special Projects Office

- AMSTE II uses an integrated, system-of-systems approach
- Innovative solutions are desired
- Prime contractor will develop and integrate all required technologies
- AMSTE concept is demonstrated through annual experiments of increasing complexity

AMSTE II will demonstrate an affordable moving surface target engagement solution

AMSTE II Bidders Briefing

Special Projects Office

9:00 am	Welcome and Administrative Comments	
9:15 am	DARPA/SPO Overview	Stephen Welby, DARPA
9:30 am	AMSTE Introduction	Stephen Welby, DARPA
Break		
10:30 am	AMSTE I Program Elements	Jon Jones, AFRL
10:40 am	AMSTE I Results	Robert Enders, MITRE
11:40 am	AFRL Capabilities and Data	Jon Jones, AFRL
12:00 pm	Moving Target Features	Rob Williams, AFRL
Lunch		
1:30 pm	AMSTE II Description	Stephen Welby, DARPA
Break		
2:45 pm	Proposal/Contract Requirements	Jon Jones, AFRL
3:15 pm	Closing Comments	Stephen Welby, DARPA

Special Projects Office

AMSTE II
Proposal and Contract Requirements

Jon Jones, AFRL

Proposal Instruction

- AMSTE II PRDA
- Proposal Information
- Statement of Work
- Proposal Evaluation
- Security
- Conclusion

AMSTE II PRDA

- The AMSTE II PRDA was formally published on 23 June 2000
  - Technical Proposals MUST include both Phase I and Phase II Programs
  - Full Cost Proposal for Phase I Program (Part I of the PRDA)
  - Detailed ROM Cost for Phase II Program (Part II of the PRDA)
  - Proposals are Due 30 August 2000

- Progressive contracting process that encompasses two parts:
  - Part I is for the First Year Program and has a one year schedule
  - Part II is for the Second Year Program and also has a one year schedule
  - A separate proposal (update or new) for Part II is due on 1 July 01
    - Additional information on this proposal is provided later in the briefing

Proposal Information

- Proposals are due 30 August 2000, 1600 EDT
- Proposals must include three items:
  - Statement of Work (Part I)
  - Technical Proposal (Part I and Part II)
  - Cost Proposal (Full Part I, ROM for Part II)
  - Technical and Cost Proposals are separate volumes
    - Gov't needs to be able to separate the proposals
  - Technical proposals are limited to 75 pages excluding resumes and Statement of Work
    - Use 12 pt.or Larger font
      - » Graphic Material May Be Smaller (Use Judgement)
    - Double-space lines
    - No page limit has been set on the Statement of Work
    - Fold Outs are Acceptable, Count as One Page

The objective is for a quality proposal evaluation process

Proposal Information
(Continued)

- The offeror’s technical proposal shall:
  - Describe the proposed experimental system, list the critical technologies that pertain to it, and give a plan for developing and demonstrating these technologies using the proposed system
  - List the key risks associated with the development and use of the experimental system, and how they are to be mitigated
  - Discuss the Government experiment scenarios with regard to the offeror’s desired experiment approach and anticipated requirements
  - Discuss schedule risk items and mitigation plans

Proposal Information
(Continued)

Risk \ Approach	Analysis/Simulation	Lab Testing	Field Characterization	Captive Flight Test	Other (?)
Stability of Range Calibration	X	X	X		
Carriage & Release of Experimental Weapon	X			X	X
Weapon data link Antenna pattern	X	X	X	X	
Accuracy during move-stop-move	X		X		
•					
•					

Offerors are encouraged to describe how risks would be mitigated

Proposal Information
(Continued)

- CBD, Proposal Instructions, Bidders Brief, Questions and Answers, Attendance List, etc.
  - Will be posted on the Web Site
    - http://www.rl.af.mil/div/IFK/prda/prda-main.html

- Question and Answer Session OPEN until COB 7 July 2000.
    - Questions need to be provided to Joetta Bernhard
      - » Questions can be submitted via:
        - E-Mail: Joetta.Bernhard@rl.af.mil (preferred method)
        - Phone: (315) 330-2308
        - Fax: (315) 330-7790
    - All Questions and Answers will be posted without attribution on the Web 2 business days after receipt
    - Everyone has access to all information

Proposal Information
(Continued)

- Teaming with AMSTE I Core Team members is prohibited
  - Core Team consists of SAIC, Toyon, MIT/Lincoln Lab, MITRE, Black River Systems, Booz-Allen & Hamilton
  - All will sign NDA's if necessary and are prohibited from competing on AMSTE
- If you DO NOT have web access
  - Call Joetta Bernhard and she will FAX the material
  - Phone: 315-330-2308
  - Fax: 315-330-7790
- Close of Business (COB) is 1600 EDT.
  - This is for proposal delivery and questions and answers

Statement of Work

- Statement of Work (SOW) is contractor generated
- SOW is NOT Counted as Part of the 75 Page Limit of the Technical Proposal
- Provide SOW in hard copy and electronic format on either a 3.5 floppy or a Zip disk (Microsoft Word compatible preferred)
- SOW Format:
  - 1.0 Objective
  - 2.0 Scope
  - 3.0 Background
  - 4.0 Tasks/technical requirements

Statement of Work

- Clearly define Deliverables Within the Proposal
  - Monthly Status Reports
    - Contract Schedule Status Reports (CSSR)
    - Contract Funds Status Reports (CFSR)
  - Technical Interchange Meeting
    - At a minimum, Quarterly
  - Data
  - Technical Reports every 6 Months
  - Experiments
  - Detailed WBS
- Schedule for Deliverables
  - Clearly define the schedule; this becomes part of the contract

Statement of Work Structure

1.0 Objective

1.1 The objective is to target moving surface threats from long range and rapidly engage with precision, stand-off weapons.

2.0 Scope

2.1 The scope of this effort is to develop technology and algorithms for targeting moving surface threats and to perform experiments to test and demonstrate this technology .

3.0 Background

3.1 We have been doing work in these areas that relate to this program.

3.2 Our experience and technical expertise add this to the program.

4.0 Tasks/Technical Requirements. The Contractor shall:

4.1 Develop a set of experiments for the Affordable Moving Surface Target Engagement program.

4.1.1 The experiments shall define a set of functional elements, describe each interface, and provide a method of employment.

Statement of Work
(Continued)

- The Tasks/Technical Requirements need to be specific and provide action
- Please keep background information out of the Tasks/Technical Requirements
- Use action verbs like analyze, develop, design, evaluate, provide, . . .
- Use “shall” in place of “will”
- Do not start every task off with “The contractor shall” – this goes at the top
- Do not use non-definitive verbs like study, look-at, read, . . .

Proposal Evaluation

- Proposal Evaluations
  - Evaluation of proposals will be accomplished using the following criteria:
    - Overall scientific and technical merit
    - Potential contribution and relevance to this effort
    - Innovativeness of the proposed approach and/or techniques
    - Offeror's capabilities and related experience
    - Cost realism and reasonableness
  - All criteria are weighted evenly
  - There is no list of priority

Part II of the AMSTE II PRDA

Special Projects Office

- Proposals are due 1 July 2001, 1600 EDT
- Proposals must include three items:
  - Statement of Work
  - Technical Proposal
  - Full Cost Proposal
- Technical and cost proposals are separate volumes
  - Gov't needs to be able to separate the proposals
- Technical proposals are limited to 75 pages excluding resumes and Statement of Work
  - Use 12 pt.or Larger font
    - » Graphic Material May Be Smaller (Use Judgement)
  - Double-space lines
  - No page limit has been set on the Statement of Work
  - Fold Outs are Acceptable, Count as One Page

Part II Proposal Evaluation

- Proposal Evaluations
  - Evaluation of proposals will be accomplished using the following criteria:
    - Progress towards second year experiment
    - Overall Scientific and technical merit
    - Cost realism and reasonableness
  - All criteria are weighted evenly
  - There is no list of priority

Security

- We can accept classified proposals
  - Be sure classified proposals are properly marked
    - Be sure to identify Security Classification Guide (SCG) and proper downgrading instructions
  - Classified proposals higher than SECRET collateral must be coordinated through Contracting Officer
    - Call Joetta Bernhard 315-330-2308

Conclusion

- Affordable Moving Surface Target Engagement II (PRDA 00-05-IFKPA)

- Proposals are due 30 August 2000, COB is 1600 EDT (4:00 p.m.)
  - 75 page limit on technical proposals, 12 pt. font, double-spaced
  - No page limit on Cost Proposal

Conclusion
(continued)

- Be sure to address evaluation criteria
  - Overall scientific and technical merit,
  - Potential contribution and relevance to this effort,
  - Innovativeness of the proposed approach and/or techniques,
  - Offeror's capabilities and related experience, and
  - Cost realism and reasonableness

- All our information is posted on the web
  - http://www.rl.af.mil/div/IFK/prda/prda0005.html

- Contracting schedule is aggressive
  - The more organized the proposal, the quicker we can get on contract
  - This includes clearly spelled out requirements and deliverables
    - Government Furnished Property
    - Data Deliverables

AMSTE II
Bidders Briefing

Special Projects Office

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Special Projects Office

AMSTE II Closing Comments

Stephen Welby, DARPA

AMSTE Focus

Target *moving* surface threats from long range and rapidly *engage* with precision, stand-off weapons

Key AMSTE Characteristics:

***All-Weather Engagement*:**	**Requires use of multi-laterated, geo-registered GMTI sensors**
***Targeting Focused*:**	**Requires ability to maintain threat track from nomination through engagement**
***Precision Engagement*:**	**Requires ability to provide fire control updates to weapons in flight**

AMSTE Technologies support a seamless moving target engagement from Nomination → Track Maintenance → Engagement

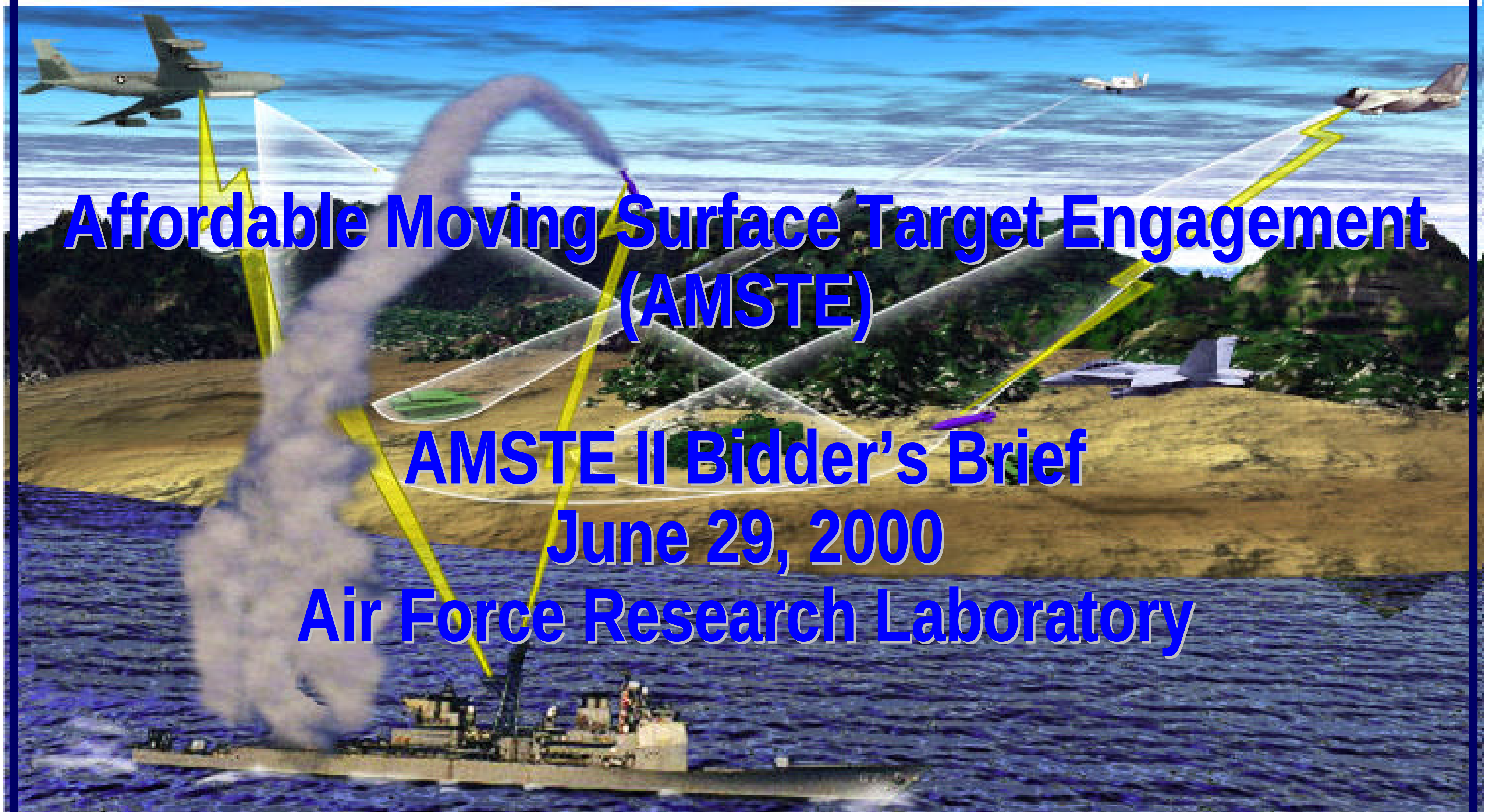
AMSTE Program Summary

Special Projects Office

- AMSTE I showed the feasibility of moving target engagement
  - Precision fire control supports <10m HTLE
  - Various architectures are viable
- AMSTE II uses a system-of-systems approach
  - Netted sensors enable robust solutions
  - Kill chain transitions and tasking need to be seamless
- Technical challenges remain
  - Large integration effort
  - Real time battle management
  - R&D efforts for track maintenance

DARPA

SPO
Special Projects Office



Affordable Moving Surface Target Engagement (AMSTE)

AMSTE II Bidder's Brief
June 29, 2000
Air Force Research Laboratory